Forest EcoValue

28/11/2025
Document Version: 0.1

FOREST ECOSYSTEM SERVICES ASSESSMENT PILOT ACTION REPORT

D.2.2.1

RESPONSIBLE PARTNER: INRAE / PP4

DISCLAIMER

THIS DELIVERABLE D.2.2.1 (VERSION 1) WILL UNDERGO FURTHER REFINEMENT AND INTEGRATION UNTIL THE END OF THE FOREST ECOVALUE PROJECT. THE FINAL VERSION WILL REPLACE THIS ONE ON THE PROJECT WEBSITE AND WILL BE MADE AVAILABLE BY APRIL/MAY 2026.

Interreg Co-funded by the European Union
Alpine Space

Forest EcoValue

28/11/2025
Document Version: 0.1

Interreg Alpine Space Programme 21-27

Carbon neutral and resource sensitive Alpine region
SO 2.2: Promoting the transition to a circular and resource efficient economy

Forest EcoValue:
Supporting multiple forest ecosystem services through new circular/green/bio markets and value chains

Project ID: ASP0100005

List of the Forest EcoValue project partners

PP1. Finpiemonte SpA – Regional financial and development agency / **Coordinator** [FINPIE]
PP2. Lombardy Foundation for the Environment – Fondazione Lombardia per l'Ambiente [FLA]
PP4. National Research Institute for Agriculture, Food and Environment – Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement [INRAE]
PP5. Slovenia Forest Service – Zavod za Gozdove Slovenije [ZGS]
PP6. Institute for Environmental Planning and Spatial Development GmbH & Co. KG – Institut für Umweltplanung und Raumentwicklung GmbH & Co. KG [Ifuplan]
PP7. Lombardy Green Chemistry Association – Cluster Lombardo della Chimica Verde [LGCA]
PP8. University of Graz, Institute of Environmental Systems Sciences [UNIGRAZ]
PP9. Regional Centre for Forest Property Auvergne-Rhône-Alpes – Centre Régional de la Propriété Forestiére [CNPF]
PP10. The French National Forest Office – Office National des Forêts [ONF]
PP11. Hozcluster Steiermark – Woodcluster Styria [HCS]

Document information

Work package:	WP2 Testing an economic approach for managing FES in a network of Living Labs (LLs)
WP lead:	PP6
Activity:	A.2.2.
Authors:	Deliverable edited by the Forest EcoValue project partners under the supervision of WP leaders
Main contributor(s):	Frederic Berger (PP4)
Reviewers:	Reviewed by PP6
Document version:	Version 1
Due date (month)	36
Actual delivery date (month):	28/11/2025
Deliverable number:	D.2.2.1
Dissemination Level:	PU: Public (available on the project website)
Type	Report

Disclaimer
This activity was co-funded by the Interreg Alpine Space Programme 21-27. The views and opinions expressed in this document are solely those of the author(s) and do not necessarily reflect those of the Alpine Space Programme bodies or the project partners' regions. Neither the Alpine Space Programme and its bodies nor any person acting on their behalf may be held responsible for the use of the information contained herein.

Summary

<

1. Introduction

The Forest Eco Value project aims to enhance the understanding and quantification of forest ecosystem services (FES) through an integrated approach combining spatial analysis, biophysical assessment, economical assessment and stakeholder engagement. Forest ecosystems provide a wide array of services—ranging from carbon sequestration and biodiversity conservation to recreation and water regulation—that are essential for both environmental sustainability and human well-being. Despite their critical importance, these services are often undervalued or insufficiently integrated into policy and management frameworks.

Deliverable D2.2.1 constitutes a core output of the project's Work Package 2, focusing on the mapping and biophysical assessment of selected FES. This deliverable consolidates the methodological approaches, data processing workflows, and analytical results derived from the Living Labs established across different biogeographical regions. Each Living Lab served as an experimental platform for co-developing and testing assessment methodologies in collaboration with local stakeholders, thereby ensuring both scientific robustness and practical relevance.

The outcomes presented in this report provide a comprehensive overview of the spatial distribution and biophysical performance of key forest ecosystem services. Furthermore, they establish the foundation for subsequent valuation and policy integration activities, supporting evidence-based decision-making and sustainable forest management within the framework of the Forest Eco Value project.

2. Project overview

Forests of the Alpine Space play a key role in climate change mitigation and resilience, providing multiple ecosystem services (ES) and environmental and social benefits such as CO_2 absorption, air pollution reduction, biodiversity enhancement, and protection against natural hazards. However, they are threatened by abandonment, climate change, and territorial degradation, which progressively reduce natural resources and the provision of ES. Maintenance costs of Alpine forests are high, and public funds and traditional wood value chains are insufficient to cover them. Economic valuation and payment schemes for ES are widely discussed but rarely successfully applied.

The Forest EcoValue project addresses this challenge by developing innovative, sustainable business models for forest management and maintenance, supporting new bio-based value chains and ES markets, and involving different sectors, public and private actors, and citizens. Restoring and maintaining healthy forests has been recognized as a source of value for the Alpine region, while also creating business opportunities and green jobs for Alpine communities.

The project focuses on a subset of Forest Ecosystem Services (FES) from the following categories:

- **Provisioning** (e.g., biomass, raw materials, chemicals) with a specific focus on non-timber forest products, and on the production of woody biomass for energy, integrated into circular energy markets.
- **Regulation** (e.g., biodiversity, natural risk reduction, CO_2 absorption) concretely working on carbon and biodiversity credits, natural risk management through protective forests, and innovative environmental finance instruments such as green bonds and reverse auctions.

- **Cultural** (e.g., recreation, habitat experience, health) particularly enhancing recreational and tourism services and spiritual and cultural services.

These services have been explored and tested in five pilot Living Labs, located in different Alpine territories and representing diverse ecological and socio-economic contexts:

- **France - Haute-Savoie:** Grand Annecy and Thonon Living Lab focuses respectively on two aspects 1) recreational ecosystem services, enhancing the value of forests through the sale of experiences such as ecotourism, outdoor activities, and educational programs 2) enhancing the value of water regulation services through a public-private partnership.
- **Italy – Alta Valle Tanaro, Piedmont:** The Living Lab in Valle Tanaro explores innovative approaches to valorizing chestnut groves, promoting non-timber forest products, developing carbon and biodiversity credits, and fostering experiential activities linked to forest and rural heritage.
- **Germany – Tegernsee Valley, Upper Bavaria:** The German Living Lab explores spiritual and cultural services, such as forest cemeteries with biodegradable urns, while also fostering habitat and biodiversity conservation through collaborative public–private partnerships.
- **Austria – Province of Styria:** The Styrian Living Lab concentrates on biodiversity and habitat conservation through innovative financing mechanisms such as reverse auctions, while also testing carbon sequestration and stability tools like green bonds.
- **Slovenia – Karavanke Mountains, Northern Slovenia:** The Slovenian Living Lab addresses natural risk management through protective forests and develops models for producing woody biomass for energy, integrating forest resources with local energy markets.

Accordingly, the project is aiming to:

- Map and analyze the Alpine Space Forests (ASF) delivery capacity of FES;
- Identify and estimate the economic potential, define business models and FES market frameworks;
- Test the models/tools developed by the consortium in pilot living labs (LLs) involving local players;
- Compare results at transnational level, identifying obstacles and facilitating factors;
- Analyze the need for innovative policies to foster forest maintenance, ES markets, and new value chains;
- Elaborate refined transferable tools/models and policy proposals to enable new markets and value chains and ensure the expected ES.

Throughout the project, a continuous participatory process is carried out within the five pilot Living Labs. Stakeholders' active involvement in these labs is essential for co-designing and testing models and tools, ensuring that the innovative approaches are rooted in local realities. In parallel, public events and capacity-building workshops have strengthened engagement, supported knowledge transfer, and provided regular updates on project activities. This participatory and long-term approach, tested across the five territories, is paving the way for refined, transferable tools and policy proposals that can unlock new markets and value chains while safeguarding the provision of ecosystem services in the Alpine Space.

Project duration: 42 months

Disclaimer regarding the conditions and limitations governing the use of the data and analytical tools presented in this document.

The data, analyses, and tools included in this document are provided for informational purposes only. While every effort has been made to ensure their accuracy and reliability, they are provided "as is" without any warranty, express or implied, including but not limited to warranties of merchantability or fitness for a particular purpose.

Users are solely responsible for how they interpret and use the information contained herein. The authors and publishers of this document accept no liability for any loss or damage arising directly or indirectly from the use of the data or analytical tools provided.

Any reproduction, distribution, or use of the contents of this document must comply with the applicable legal and contractual obligations. Use of the data or tools for commercial, regulatory, or decision-making purposes should be undertaken with caution and, where necessary, supplemented by independent verification or expert advice

3. Concise overview of the project's Living Labs (LLs)

3.1 Living Labs: A European Approach to Innovation in Environment and Forestry

3.1.1 Definition and European Perspective

According to the European Network of Living Labs (ENoLL), Living Labs are user-centered open innovation ecosystems that integrate research and innovation in real-life communities and settings. Unlike traditional laboratories, they operate within everyday environments and actively involve end-users from the earliest stages of design, experimentation, and validation of new products, services, and policies.

Key features of a LL are:

- Co-creation / Open innovation: collaboration between public actors, private companies, academia, and citizens (the so called: Quadruple Helix model).
- Real-life environments: experimentation takes place in authentic settings, not confined to laboratories.
- Multi-method approaches: combining field observation, prototyping, surveys, digital tools, and participatory methods.
- Territoriality: each Living Lab is rooted in a specific socio-economic and cultural context, often addressing local challenges.

3.1.2 Evolution and Applications

The concept of Living Labs emerged in the late 1990s, notably at MIT, to study technology use in everyday contexts. In Europe, the approach was institutionalized with the creation of ENoLL (2006), reflecting the rise of open innovation and citizen participation.

Today, Living Labs are deployed across multiple domains, such as:

- Health and ageing: supporting older adults, testing healthcare innovations.
- Environment and agriculture: co-developing sustainable practices for water, soil, and biodiversity.
- Forestry and climate: designing adaptive strategies for forests under climate stress.
- Smart cities and ICT: testing mobility solutions, IoT, and public service innovations.

3.1.3 Living Labs in Environment and Forestry

Environmental and forest-related Living Labs address urgent challenges such as climate change, biodiversity loss, and conflicting uses of natural resources. They act as territorial platforms where science, policy, business, and local communities collaborate.

Governance and participation

- Based on Public-Private-People-Partnerships (4Ps).
- Involvement of diverse actors: researchers, forest managers, policymakers, industries, NGOs, and citizens.
- Emphasis on participatory governance to co-design forest strategies and reduce conflicts.

Benefits observed

- Climate resilience: adaptive silvicultural practices, mixed-species forests, ecological corridors.
- Biodiversity and ecosystem services: restoration of peatlands, forest edges, and riparian zones enhances carbon storage and ecological connectivity.
- Conflict mitigation: participatory methods help balance tourism, conservation, timber, and energy needs.
- Innovation acceleration: testing bio-based products, new monitoring tools, and circular economy models.

Challenges

- Temporal scale mismatch: long-term forest dynamics vs. short-term project funding.
- Sustainability: many labs end after grants, raising continuity concerns.
- Scalability: solutions often remain context-specific.
- Governance complexity: balancing diverging priorities across stakeholders.
- Ethical issues: ensuring fair participation, inclusiveness, and respect of local knowledge.

3.1.4 Perspectives for the Alpine Space

Living Labs are aligned with the European Green Deal, Horizon Europe, and Mission on Climate-Neutral and Smart Cities. They embody a shift towards open science, territorial innovation, and citizen engagement. The future directions are:

- Establishing long-term monitoring platforms for ecological and social impacts.
- Creating sustainable financing models (e.g., ecosystem services, carbon credits, bioeconomy).
- Expanding comparative research across regions and forest types.
- Strengthening policy integration to connect Living Lab outcomes to EU biodiversity and climate strategies.
- Embedding citizen science and indigenous knowledge in co-design and monitoring.

3.1.5 Examples of Environmental & Forestry Living Labs with alpine focus

Living Lab / Project	Region / Country	Main Objectives	Key Stakeholders	Specific Focus
Mountain Forest Living Lab	Hautes-Alpes, France (Alps)	Explore adaptation strategies for mountain forests facing droughts, pests, and storms.	INRAE, ONF, municipalities, citizens	Climate adaptation, biodiversity, multifunctional use
AlpES – Alpine Ecosystem Services LL	Alpine macroregion (FR, IT, AT, SI)	Co-design tools & policies for ecosystem services.	Municipalities, universities, NGOs, citizens	Forest services: carbon, recreation, avalanche protection
LIFE AdaptFor	Italian Alps	Develop adaptive silvicultural	Forest agencies,	Fire resilience, mixed-species forestry

		practices under climate stress.	landowners, researchers	
Waldlabor Zürich	Switzerland	Educate, experiment, and involve citizens in forest management.	Municipality, schools, NGOs, universities	Urban-forest interface, biodiversity, recreation
Austrian Forest Dialogue	Austria (Alps & pre-Alps)	Stakeholder platform for forest strategy.	Ministry of Agriculture & Forestry, NGOs, industry	Sustainable governance, bioeconomy, Alpine resilience
Forest'Inn Lab	France (national, Alpine links)	Collaborative innovation hub for forest transitions.	AgroParisTech, SMEs, forest owners	Bioeconomy, climate-smart forestry
SUPERB – Forest Restoration	Alpine pilot sites (Slovenia, Austria)	Large-scale restoration via diversification.	EU research consortia, NGOs, landowners	Post-disturbance restoration, mixed-forest promotion

3.1.6 Some references

Björn, H., Holmgren, L., & Johansson, S. (2022). Living labs for climate adaptation in forest landscapes: Lessons from Sweden. Forest Policy and Economics, 138, 102704. https://doi.org/10.1016/j.forpol.2022.102704

European Network of Living Labs (ENoLL). (2023). About us. Retrieved from https://enoll.org

Leminen, S., Westerlund, M., & Nyström, A. G. (2012). Living Labs as open-innovation networks. Technology Innovation Management Review, 2(9), 6–11. https://doi.org/10.22215/timreview/602

Mauser, W., Klepper, G., Rice, M., Schmalzbauer, B. S., Hackmann, H., Leemans, R., & Moore, H. (2013). Transdisciplinary global change research: The co-creation of knowledge for sustainability. Current Opinion in Environmental Sustainability, 5(3–4), 420–431. https://doi.org/10.1016/j.cosust.2013.07.001

Nijnik, M., Kopiy, S., Sarkki, S., Muñoz-Rojas, J., & Miller, D. (2019). Participatory and deliberative processes for forest ecosystem services governance: Innovation by design. Forest Policy and Economics, 109, 102002. https://doi.org/10.1016/j.forpol.2019.102002

SUPERB Project. (2023). Sustainable forest management and restoration in Europe. Horizon Europe. Retrieved from https://forest-restoration.eu

Voytenko, Y., McCormick, K., Evans, J., & Schliwa, G. (2016). Urban living labs for sustainability and low carbon cities in Europe: Towards a research agenda. Journal of Cleaner Production, 123, 45–54. https://doi.org/10.1016/j.jclepro.2015.08.053

3.2 Overview of the Living Labs within the Forest Ecovalue Project

3.2.1 Key features of Haute-Savoie, Grand Annecy and Thonon Agglomération , Inter-municipal cooperation bodies, France

- Project partner in charge of the FEV activities coordination within Grand Annecy sub LL: Regional Centre for Forest Property (CNPF) with the support of PP9 French National Forest Service (ONF) PP10
- Contact person(s):
    - Lauriane HENNET
    - Nicolas ANFRAY
    - Sylvain OUGIER
- Contact email(s):
    - Lauriane.hennet@cnpf.fr
    - Nicolas.anfray@cnpf.fr
    - Sylvain.ougier@cnpf.fr
- Main characteristics of the area: Grand Annecy
    - 23000 ha of forest cover (43% of overall surface, including the Annecy Lake), distribution of forest ownership: 42% of public and 58% of private forests, 11000 private owners.
    - Coordinates: 944411,22 6536940,45
- Forest Ecosystem Services investigated:
    - Recreation
    - Biodiversity
    - Risk mitigation
    - Drinking water resource
- Goal(s) of FLL:
  Grand Annecy is a highly touristic area where forests play an important role in regional attractiveness. However, climate change threatens these forests, and many tree species may experience high mortality rates. To ensure that forests continue to provide ecosystem services, especially recreational value and landscape permanence, management actions must be undertaken. The vision of the Living Lab is to engage recreational users in forest management, fostering their sense of stewardship and ownership over the challenges facing natural ecosystems. It aims to allocate a share of the tourism tax to fund actions that support foresters and forests in coping with the impacts of tourism and outdoor activities in the region.

- Project partner in charge of the FEV activities coordination within Thonon Agglomération sub-LL: CNPF PP9
- Contact person(s):
    - Lauriane HENNET
    - Nicolas ANFRAY
    - Sylvain OUGIER
- Contact email(s):
    - Lauriane.hennet@cnpf.fr
    - Nicolas.anfray@cnpf.fr
    - Sylvain.ougier@cnpf.fr
- Main characteristics of this area:
    - 10000 ha of forest cover (40% of overall surface, including the Leman Lake), distribution of forest ownership: 13% of public and 87% of private forests, with on average 1,2ha per owner.
    - Coordinates: 960748,184 6584701,272

- Forest Ecosystem Services investigated:
- Biodiversity
- Drinking water resource
- Recreation
- Goal(s) of FLL:
  Thonon Agglomeration is a dynamic conurbation benefiting from the Geneva economic basin. Forests are an integral part of the landscape and provide recreation, water purification and biodiversity reservoirs. However, climate change threatens these forests, and many tree species may experience high mortality rates. To ensure that forests continue to provide ecosystem services, especially biodiversity for species at risks and protection of water catchment, management actions must be undertaken. The vision of the Living Lab is to further engage private forest owner in forest management through a conciliating angle with biodiversity and recreational uses. In one hand this aims at generating more opportunities for funding and on the other end intent to attract a larger ensemble of forest owners.

3.2.2 Key features of Alta Valle Tanaro LL, Piedmont, Italy

- Project partner in charge of the FEV activities coordination within this LL: PP2 + WALDEN
- Contact person(s):
  - Lucio Vaira
- Contact email(s):
  - lucio.vaira@walden.srl
- Main characteristics of this area:
  - 61% of forest cover
  - Distribution of forest ownership:
    - public property (State, Region, Provinces, Municipalities Property): 16%
    - private ownership taken over: 3%
    - other Entities: Consortia, mixed ownership (ASL, Uni., ENEL, AEM, Railways, etc.): 3%
    - other private properties, including undetected private properties, which means that their size is less than that required by the Technical Standards: 78%
  - Average forest area per type of ownership: in the case of Monte Armetta Forest Consortium, private partners own around 100-120 ha, while the municipality of Ormea owns around 1104. Outside the Consortium, ownership can be smaller.
- Forest Ecosystem Services directly investigated:
  - Fuelwood
  - NWFP provision
  - Carbon sequestration
  - Ecotourism
- Goal(s) of the LL:
  The Valle Tanaro Living Lab exists to design, test, and scale integrated forest management models that maintain and enhance key forest ecosystem services while creating tangible economic and social benefits for local communities.

3.2.3 Key features Tegernsee Valley, Upper Bavaria, Germany.

- Project partner in charge of the FEV activities coordination within this LL: ifuplan Institut für Umweltplanung und Raumentwicklung GmbH & Co. KG, PP6
- Contact person:
  - Andrea Emmer
- Contact email:

    - andrea.emmer@ifuplan.de
- Country, Region:

  Forest of Mr. L.B.:
  Germany, upper Bavaria, districts Miesbach and Bad Tölz-Wolfratshausen
  Church forest:
  Germany, upper Bavaria, 4 subparts in several districts. District Garmisch-Partenkirchen “Gstaig“, district Bad Tölz-Wolfratshausen “Buchberg” and “Endlhausen”, district München “Sauerlach”.

- Coordinates:

  Forest of Mr. L.B.:
  47.734565, 11.633211
  Church forest:
  “Gstaig”: 47.671282, 11.275191
  “Buchberg”: 47.878704, 11.450440
  “Endlhausen”: 47.942632, 11.573148
  “Sauerlach”: 47.958232, 11.673576

- Main characteristics of this area:
  As the LL area was defined by us as the forest estates of the land owners, the forest cover is close to 100 %. Mr. L. B. owns a total of 279 hectares, including 144 hectares of forest. The church forest covers 387 hectares in total, with 317 hectares designated as forested land.
  The forest share in the greater region can be average with about 51% which includes the districts Miesbach (53%), Bad Tölz-Wolfratshausen (54%), Garmisch-Partenkirchen (51%), München (44%). The forest is mainly located in the highlands, whereas the lowlands are characterized by agricultural use.
  Data on forest ownership is only available for the districts of Miesbach and Bad Tölz-Wolfratshausen, as well as for the region of Upper Bavaria. The figures for these areas are quite similar. In the two districts, there are approximately 60,000 forest owners. 41% of the forest area there, is owned by the federal state, 55% is privately owned, and 4% is owned by municipalities. In Upper Bavaria, 41% of the forest area is owned by the federal state, 50% is privately owned, 7% belongs to municipalities, and 2% is owned by the German state.
- Forest Ecosystem Services investigated:
  In the in both LLs we investigated the FES, Wood biomass production, carbon storage, recreation, drinking water provision and habitat provision.
- Goal(s) of FLL:

  Forest of Mr. L.B.:
  Forest owner L. B. aims to enhance the **recreational and educational function** of his forest by launching a “Green Initiative,” which will serve as a platform for organizing educational programs, cultural events, and nature-based experiences. By collaborating with local artists, chefs, and community groups, he wants to create opportunities for people to connect with the forest, enjoy its atmosphere, and reflect on the relationship between nature and culture. The owners motivation for launching the Green Initiative is rooted in his commitment to making forest owner perspectives accessible and relevant to the broader public. He aims to foster dialogue, inspire creativity, and strengthen the recreational and educational value of his forest for everyone.
  Church forest:
  The church aims to enhance the **FES of recreation** by establishing a burial forest that offers a natural, low-maintenance alternative to traditional burial grounds. This aligns with the forest’s conservation goals and complementing existing structures like the nearby grief counselling centre. The motivation behind this goal is to respond to growing public demand for meaningful, sustainable burial options while preserving the forest’s ecological integrity,

thus creating a space that supports both community needs and long-term forest conservation.

3.2.4 Key features of Styria LL, Austria

- Project partner in charge of the FEV activities coordination within this LL: HCS PP11 and UNIGRAZ PP8
- Contact person(s):
    - Alexander PINTER (PP11)
    - Kilian SILBERSCHNEIDER (PP11)
    - Victoria YAVORSKAYA (PP8)
- Contact email(s):
    - pinter@holzcluster-steiermark.at
    - silberschneider@holzcluster-steiermark.at
    - vctoria.yavorskaya@uni-graz.at
- Main characteristics of this area:
    - ca. 60% of forest cover
    - distribution of forest ownership: 87% of private, 9% of public and 4% municipality owned forest area; the average size of privately owned forest properties in the region is around 5–10 hectares
    - number of owners classified by type of property
    - average forest area per type of ownership: the average size of privately owned forest properties in the region is around 5–10 hectares; 55% of total forest area are small-scale forest holdings (under 200 ha), 9% of forest area is of size 200-1000 ha and 23% of forest area are large forest holdings with areas larger than 1000 ha.
- Forest Ecosystem Services investigated: habitat maintenance, carbon storage and sequestration, timber provision
- Goal(s) of LL:
    - Ecological objectives
      Conserve and restore degraded forest ecosystems, particularly those impacted by monocultures, overexploitation, or biodiversity loss, aiming to re-establish ecologically functional and climate-resilient forest stands.
      Stabilize the carbon cycle through continuous cover forestry and diversified forest structures.
      Enhance biodiversity by preserving and improving habitats, tree species diversity, and structural complexity.
    - Economic objectives
      Create new funding opportunities for sustainable management and ecosystem service provision.
      Demonstrate viability, cost-efficiency and socio-ecological effectiveness of the of the proposed business model(s).
      Simplify procedures and improve advisory services to make sustainable forestry and ecosystem-based business models more accessible—especially for small-scale forest owners.
      Strengthen interest in active forest management, especially among owners with low management intensity or limited technical capacity.
      Support small-scale private forest owners, especially in implementing climate-adaptive and biodiversity-promoting measures.
      Ensure continuity of the pilot beyond the project duration, through stakeholder commitment and financial sustainability.

3.2.5 Key features of Karavanke Mountains, municipality Tržič LL, Slovenia

- Project partner in charge of the FEV activities coordination within this LL: Slovenia Forest Service (SFS) PP5
- Contact person(s):
  - Živa BONČINA
  - Tina SIMONČIČ
- Contact email(s):
  - tina.simoncic@zgs.si
  - tina.simoncic@zgs.si
- Main characteristics of this area:
  - 73% of forest cover
  - Tree species composition (% of growing stock): Norway spruce 60.0%, European beech 21.4%, silver fir 8.1%, noble broadleaves 2.2%, hard broadleaves 1.6%, larch 3.7%, pine ssp. 1.3%, oak ssp. 1.1%
  - Ownership: 85.5% private, 9.7% state, 4.7% municipality (more than 2000 forest owners)
- Forest Ecosystem Services investigated: wood biomass, natural hazards (torrent management), recreation and tourism
- Goal(s) of FLL:
  - WOOD BIOMASS
    Our objectives are to improve the assessment of potentials and demands for wood biomass within the municipality, to raise awareness among stakeholders—particularly the municipality—about the use of wood biomass, to activate sustainable forest management, and to generally promote the use of woody biomass.
    Biomass as a renewable energy source is supported by both the EU and national policies. The Municipality of Tržič is highly suitable for the use of wood biomass, as it is extensively forested and has a favorable ownership structure. Low-quality wood has traditionally been used for firewood, with part of it sold on the market. However, the municipality lacks major consumers of low-quality wood, such as wood-processing companies or larger municipal district heating systems based on wood biomass.
  - NATURAL HAZARD – TORRENT MANAGEMENT
    Our goal (beyond the scope of the current project) is to establish a system for torrent management. Within the project, we aim to initiate training for staff, strengthen collaboration with the water management sector, prepare forms for torrent inventory, identify problematic torrents, conduct field examination of problematic torrents, and assess the staffing and cost requirements at the level of the Slovenian Forest Service, as well as the need for additional silvicultural work in torrent-prone areas.
    Slovenia does not have a functioning system for torrent management, although in the past this field was managed by the state-owned company PUH. Torrent management is an intersectoral issue, where responsibilities between the water management sector, the forestry sector, forest owners, municipalities, and the state remain unclear. Increasingly frequent natural disasters—especially the catastrophic floods of August 2023—provide additional motivation to focus on preventive measures against torrent-related damage. Preventive actions are far less costly than disaster recovery and help reduce future risks. The management of protective forests, which also include torrent-prone areas, already involves many measures that mitigate the harmful impacts of torrents both within forests and downstream.
  - RECREATION AND TOURISM
    We aim to foster recreation and tourism that are harmonized with forestry and other land uses. During the project, we seek to gather information on different stakeholders in the

fields of recreation and tourism, connect these stakeholders, assess recreation in forests, and develop strategies to reduce potential conflicts among different land users.
Forest visitation is steadily increasing, bringing with it new forms of land use that are not always harmonized. At the same time, forest areas represent significant potential for diverse entrepreneurial initiatives.

4. Methodology: Scaling from Large-Scale Data (LSD) and maps to Local-Level Analysis (LLA)

4.1 Methodological principle employed in the project for mapping and assessing Forest Ecosystem Services with LSD

By INRAE

4.1.1 Data Documentation

Dataset: ForestEcoValue_data_europe
Version: 0.1
Date: 15 June 2025
Prepared by: Baptiste Desbuquois, Frederic Berger (INRAE)
Contact: baptiste.desbuquois@inrae.fr

4.1.2 Dataset Overview

- Dataset Title: ForestEcoValue_data_europe
- Dataset access: The dataset will be made available as of 30 April 2026 through the WebAtlas of the Interreg Alpine Space Mosaic project (https://alpineresilience.org/data).
- Date of Creation: 11 December 2024
- Latest Update: 10 October 2025
- Contact Person: Baptiste Desbuquois, INRAE
- Contact Email: baptiste.desbuquois@inrae.fr

4.1.3 Methodological Information

4.1.3.1 Environmental / Experimental Context

The dataset provides a comprehensive mapping of forest-based ecosystem services across territories involved in the Living Labs of the ForestEcoValue project.

4.1.3.2 Data Sources and Methods

The dataset consolidates multiple data sources and spatial analyses (For more detailed information, readers are encouraged to refer to the project’s deliverable D.1.2.1 : Report on biophysical foundations and methodologies for the assessment of selected FES) including:

- Interreg Alpines Space project AlpTrees data set provided by CEREMA (with a specific attention paid to timber stock datasets for estimating timber and carbon values).
- OpenStreetMap-derived layers for proximity and visibility analyses.
- Natura 2000 and national protected area databases.
- INRAE (Interreg Alpines Space project RockTheAlps) spatial analysis for identification of protective forests against rockafall risks.
- For the torrential hazard protection service, which applies only to the Slovenian FLL, the data, along with the analysis methodology employed, are presented in Appendix 1 of this document.
- QGIS and DTM-based visibility analyses using OSM viewpoint points.
- Dataset (from 2017 to 2023) on forest biomass, stock volume, growing stock available via the Forest Carbon Monitoring portal: https://portal.forestcarbonplatform.org/

4.1.3.3 Data Quality Assurance

The dataset reflects the best approximations and models available at the time of its production. It is not meant to replace any field measure and can never be better than local expertise

4.1.3.4 Contextual Background

The dataset was developed as part of the FORESTECOVALUE project under the Interreg Alpine Space programme.

This dataset provides an essential foundation for assessing ecosystem services delivered by forests in the Alpine Space and at a regional scale. It brings together a wide range of reliable and harmonized spatial sources, enabling the exploration of ecological, economic, and social dimensions. By integrating information on carbon storage, landscape visibility, proximity to protected areas, and other environmental indicators, it offers a robust decision-support tool for stakeholders involved in sustainable forest management.

Beyond its application within the FORESTECOVALUE project, this dataset can also serve as a reference for other regional or European initiatives aiming to enhance the multiple functions of forest ecosystems. It represents a solid starting point for improving our understanding of the interactions between ecosystem services and land-use planning.

4.1.4 Data Overview

4.1.4.1 File Naming Convention

Files are named using the structure: data_countryname (e.g., data_france.shp). the data that has been produced are used the data alleviable for the area of interest. So, some maps can be missing if the data were not alleviable.

4.1.4.2 Layer-Specific Metadata

Layer: forest data

To build this map we used, CEREMA data about timber stock stored into the INTERREG MOSAIC web atlas. A multiplication of this volume by 0.475 has been done to calculate the carbon storage masse. This gives us the following attribute table for this layer

Variable	Description	Unit
FID	Polygon identifier	-
mean_value	Mean timber stock (CEREMA)	m^3/ha
carbon_stored	Carbon stored (47.5.% of the timber stock)	t/ha

Layer: large_visibility_50m

For this layer an extraction of the circulation path of open street map using the request access in quickOSM on qgis. We the applied a 50m buffer on all access and extract the area that where in the forest. With those remaining area we got the following attribute table:

Variable	Description	Unit
fid	Polygon identifier	-

Layer: short_visibility_20m

For this layer an extraction of the circulation path of open street map using the request access in quickOSM on qgis. We the applied a 20m buffer on all access and extract the area that where in the forest. With those remaining area we got the following attribute table

Variable	Description	Unit

fid	Polygon identifier	-

Layer: protected area

This layer is composed by the shapes of the protected area of the living lab. Most are alleviable on N2000 web site. The total layer is resampled to be only on forest and so keep the high protection status forest with the following attribute table

Variable	Description	Unit
FID	Polygon identifier	-
SITECODE	Natura 2000 site code	-
SITENAME	Site name	-
MS	Country code	-
SITETYPE	Type of habitat protection	-
INSPIRE_ID	INSPIRE-compliant site identifier	-

Layer: riparian forest

This layer is constructed form the map of the river obtain with the request: "waterway" in QUICKOSM plugin form QGIS. From Those rivers a 20m buffer is added. To this polygon, we extract only the area whit forest. We then get the riparian forest layer with the following attribute table:

Variable	Description	Unit
FID	Polygon identifier	-
name	River name	-

Layer: protective forest

For this layer we use the row data form the ALPTREES INTERREG program. The maps provided are resampled on the LivinbgLabs area and identified with this attribute table:

Variable	Description	Unit
fid	Polygon identifier	-
NUTS_ID	European NUTS region identifier	-
source	Source of the data	-
S_km2	Surface area of protective forest	km^2

Layer: visibility

This layer has been build using the viewpoints extract using the research "tourism, viewpoints" in the plug in QICK OSM form QGIS those viewpoints are used to calculate along with the DTM are used as an entry in the plug in Visibility analysis to calculate the number of viewpoints from which the polygon is visible. This gives us the following attribute table:

Variable	Description	Unit

fid	Polygon identifier	-
DN	Number of viewpoints from which the polygon is visible	-

4.1.5 Indicators associated with each studied FES

To enable systematic comparison among the various FES and to standardize the presentation of results, a set of dendrometric parameters was quantified for each living lab. These parameters were computed for each of the mapped FES zones and are hereafter referred to as "indicators."

For each FES/LL, the indicators are presented as follows:

Total for the Living Lab	**Biodiversity/Habitat support**	**Protection against natural hazards**	**Production (biomass, carbon)**	**Tourism/Recreation**
Total area (ha)				
mean carbon stored (t/ha)				
mean timber stock (m^3/ha)				
mean annual growing stock (m^3/ha.year): high-range estimate				
mean annual growing stock (m^3/ha.year): mid-range estimate				
mean annual growing stock (m^3/ha.year): low-range estimate				
Carbon sequestration (T/ha.year): high-range estimate				
Carbon sequestration (T/year): mid-range estimate				
Carbon sequestration (T/ha.year): low-range estimate				
FES in % of the total forest area				

Total for the Living Lab	Deciduous stand	Coniferous stand	Mixed stand
Total areal (ha)			
mean carbon stored (t/ha)			
mean timber volume (m^3/ha)			

mean annual growing stock (m^3/ha.year): high-range estimate			
mean annual growing stock (m^3/ha.year): mid-range estimate			
mean annual growing stock (m3/ha.year): low-range estimate			
Carbon sequestration (T/ha.year): high-range estimate			
Carbon sequestration (T/year): mid-range estimate			
Carbon sequestration (T/ha.year): low -range-estimate			
% of forest stands			

FES « XXX »	Deciduous stand	Coniferous stand	Mixed stand
Total areal (ha)			
mean carbon stored (t/ha)			
mean timber volume (m^3/ha)			
mean annual growing stock (m^3/ha.year): high-range estimate			
mean annual growing stock (m^3/ha.year): mid-range estimate			
mean annual growing stock (m^3/ha.year): low-range estimate			
Carbon sequestration (T/ha.year): high-range estimate			
Carbon sequestration (T/ha.year): mid-range estimate			
Carbon sequestration (T/ha.year): low-range estimate			
% of forest stands			

For the Growing Stock Volume (GSV) and mean annual increment, we used data published by the platform of the European Forest Carbon Monitoring project (https://www.forestcarbonplatform.org/).

These data are generated using the BIOMASAR method, which is based on Sentinel-1 and ALOS-2 PALSAR-2 observations at a 20-metre resolution. BIOMASAR is an algorithm that estimates various forest variables—such as GSV and above-ground biomass (AGB)—using canopy density and height as input parameters.

We extracted the relevant data for 2017 and 2023 within the geographical extent of the LLs. The variation in GSV between these two years was computed by subtracting the 2023 values from the 2017 values.

A biomass decrease mask (also provided by the Forest Carbon Monitoring platform) was then applied to retain only areas that had not been affected by forestry operations or storm damage. Finally, we kept only the pixels showing a positive variation, in order to identify areas of forest growth. Using the documentation available on this site, we also calculated three estimation categories:

- a high-range estimate, corresponding to the result obtained directly from the raw data available on the platform,
- a mid-range estimate, corresponding to the application of a corrective factor of 86.80%,
- a low-range estimate, corresponding to the application of a corrective factor of 63.43%.
- Note: a very low-range estimate can also be calculated using a corrective factor of 45,99%. This estimation is not presented in the tables given for each FLL.

These three categories have a direct impact on the assessment of carbon sequestration, since sequestration is calculated from the average annual increment. The same applies to assessing the volume of wood that can be mobilized for energy purposes. The percentage of annual growth allocated to fuel wood is a local figure which, if known, can then be used together with the growth data we provide

Since these data are initially derived from the analysis of satellite imagery, the accuracy of the estimates depends directly on the quality of the input data, which may vary within a single image (variable viewing angle, presence of clouds or shadowed areas, etc.). Thus, for each territory, the choice of which estimation category to use must be made according to the locally, regionally, or nationally available data. In all cases, the choice should ensure that the resulting order of magnitude remains consistent.

For the rockfall hazard protection service (as a reminder, the German Living Lab is not concerned by this FES) a complementary indicator was calculated based on the nature of the assets being protected. For road networks, this indicator corresponds to the percentage of total road length that is potentially protected by upstream forested areas. To compute this indicator, the total length of the road network and the portion of that length potentially protected by forested areas were calculated, and the ratio of protected length to total length was then expressed as a percentage.

With regard to buildings, only the total number of buildings potentially protected was calculated. These are buildings located (1) within a maximum rockfall propagation zone—without accounting for the effect of forest vegetation in the simulation work—and (2) downstream of a forested slope. The results were then grouped into numerical classes. Only the French living lab is concerned by this indicator.

For the torrential hazard protection service, which applies only to the Slovenian FLL, the indicators are expressed without counting the protected assets. They were established (1) for forest areas that can supply woody debris to watercourses (torrents/rivers)—thus requiring specific maintenance to avoid increasing the hazard—and (2) for forest sectors within the drainage basins of the watercourses. The total surface area of the protected zone was calculated. This approach was selected for this ecosystem service given that the statistical model used is currently undergoing operational testing.

For the Drinking Water Resource service, due to the sensitive nature of this resource, the mapping data required for the biophysical assessment of this FES are, depending on the country and territory, subject to access restrictions and therefore not available. Given this situation, a simple and operational—though non-cartographic—methodology is proposed. It is based on (1) the observation that water captured from forest springs is of higher quality and requires little or no purification, and (2) the type and minimum level of data that the stakeholders of the study area are able to provide.

This methodology relies on the total drinking water consumption of the study area, the share coming from forest water intakes (also known as water collection point), and the potential to create new intakes in forested zones. For the study area, the data that are both necessary and sufficient are: the total forest area, the surface area of protection perimeters for forest water intakes, the total drinking water consumption from all production sources combined (forest spring intakes, karstic gravity-fed springs, boreholes, surface-water pumping, etc.), and the percentage share of “forest water” in the total production. These data make it possible to assess, both in terms of production share and proportion of forest area, the importance of this FES at the scale of the study area.

A prospective analysis can be carried out if the number or percentage of forest springs that are currently uncaptured is available. To estimate the forest area associated with these potential new forest water intake zones, and provided that the geographic coordinates of the springs are known, a 3-km-radius buffer can be created around each spring (this distance is non-planimetric and therefore requires a digital elevation model to compute the buffer along the slope). The results of this buffer can then be intersected with the watershed (also known as the drainage basin) feeding each spring, in order to estimate the potentially concerned forest area.

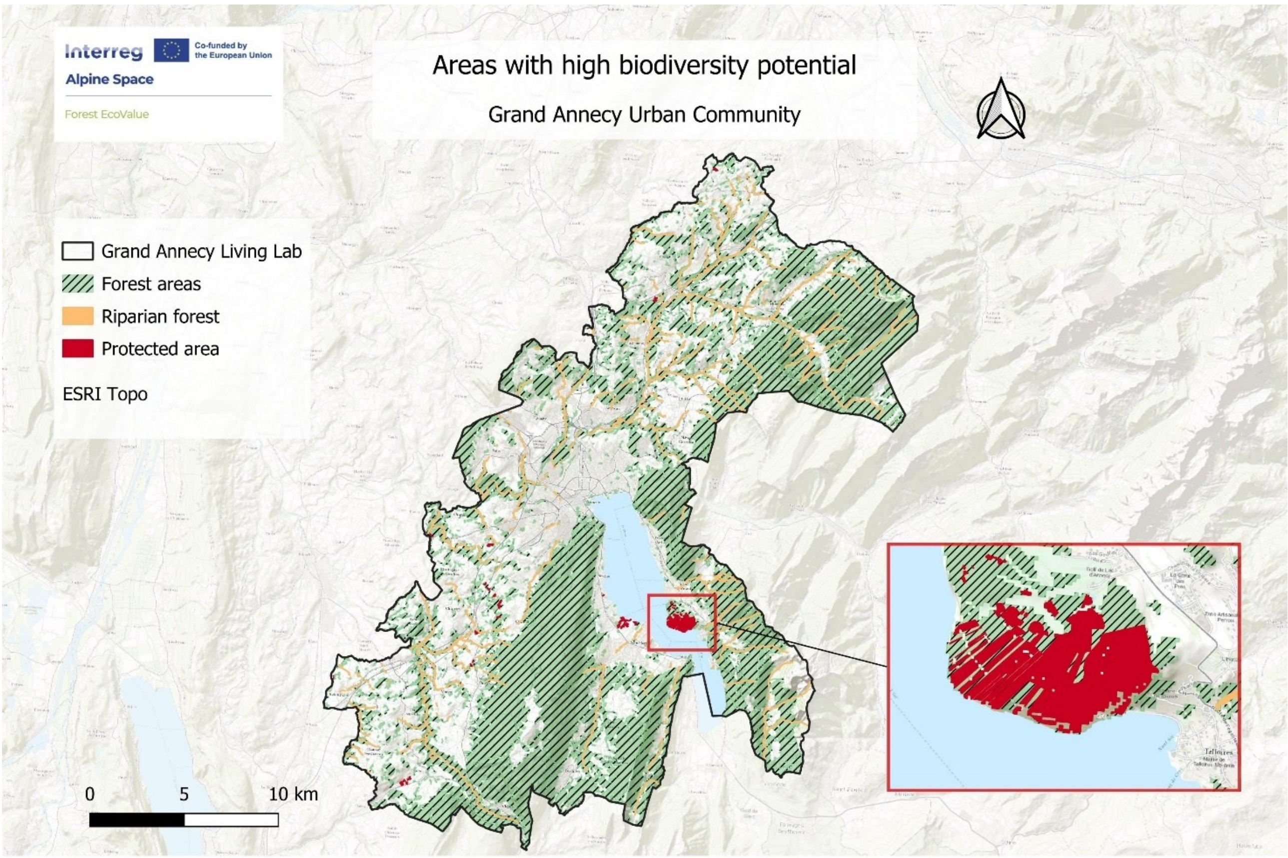
If, for the study area, all data are available as GIS-ready geographic information layers, it becomes possible to compute for these forest areas the same indicators presented in the three tables above, thus harmonizing the presentation of results with those of the other ES assessed in the territory.

5. Overview of the FES mapped outputs and indicator results for each Living Lab

This section of the report provides, for each Living Lab, an overview of the maps generated for a standardized set of 5 forest ecosystem services, with two supplementary services incorporated specifically for the Slovenian Living Lab (protective forest against snow avalanches and protective forest against torrential hazards). Depending on the countries, some spatial data on water-related services are not publicly available; however, indicators (Forest composition types: deciduous, mixed, and coniferous) have been calculated that can serve as proxies to assess the potential of water-related forest ecosystem service.

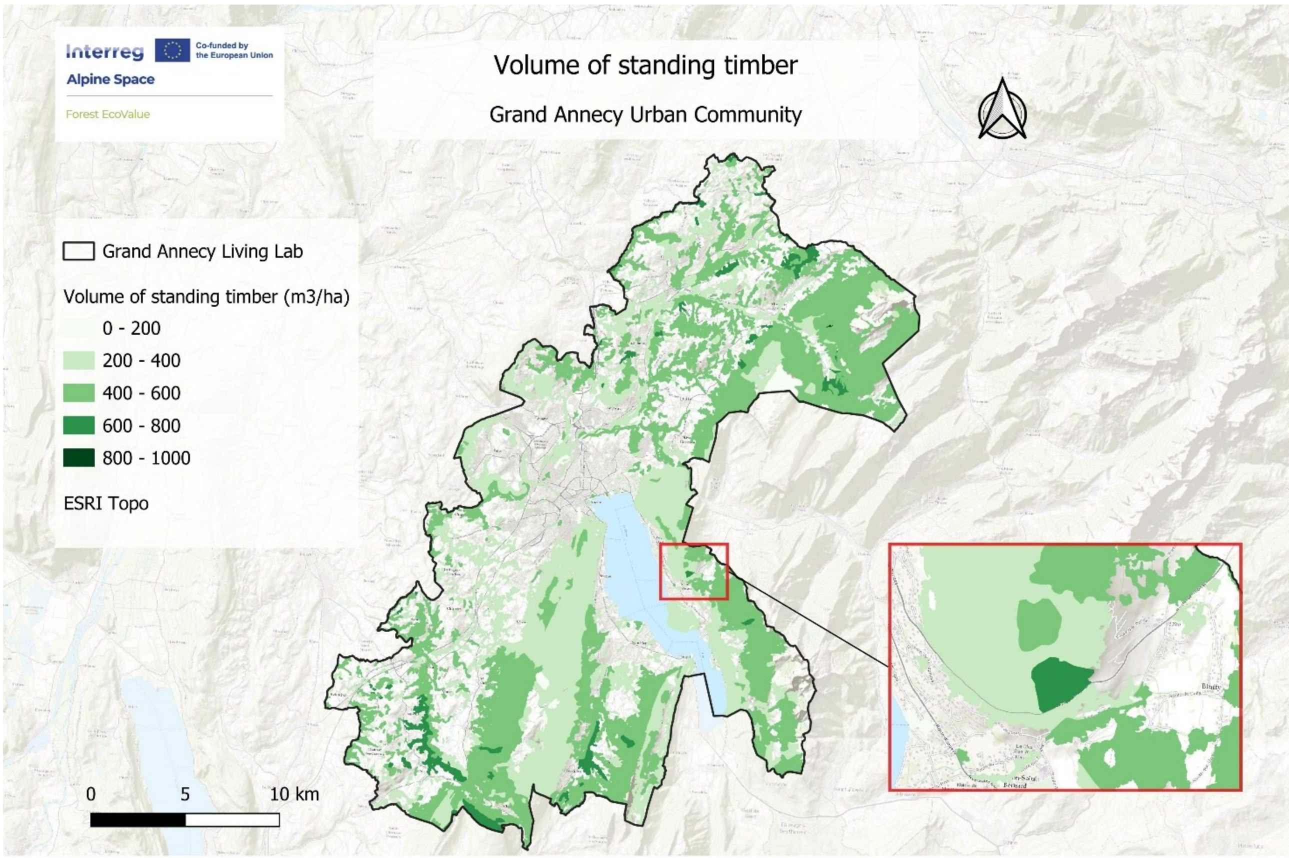
5.1LL1a: Grand Annecy France

- FES1: map of forest areas with high biodiversity and habitat support potential (support service)



Sources :
IFN : stands ; SANDRE : Waterourses ; Natural History Museum : Protected areas (Natura 2000)
Production : INRAE, Nov 2025

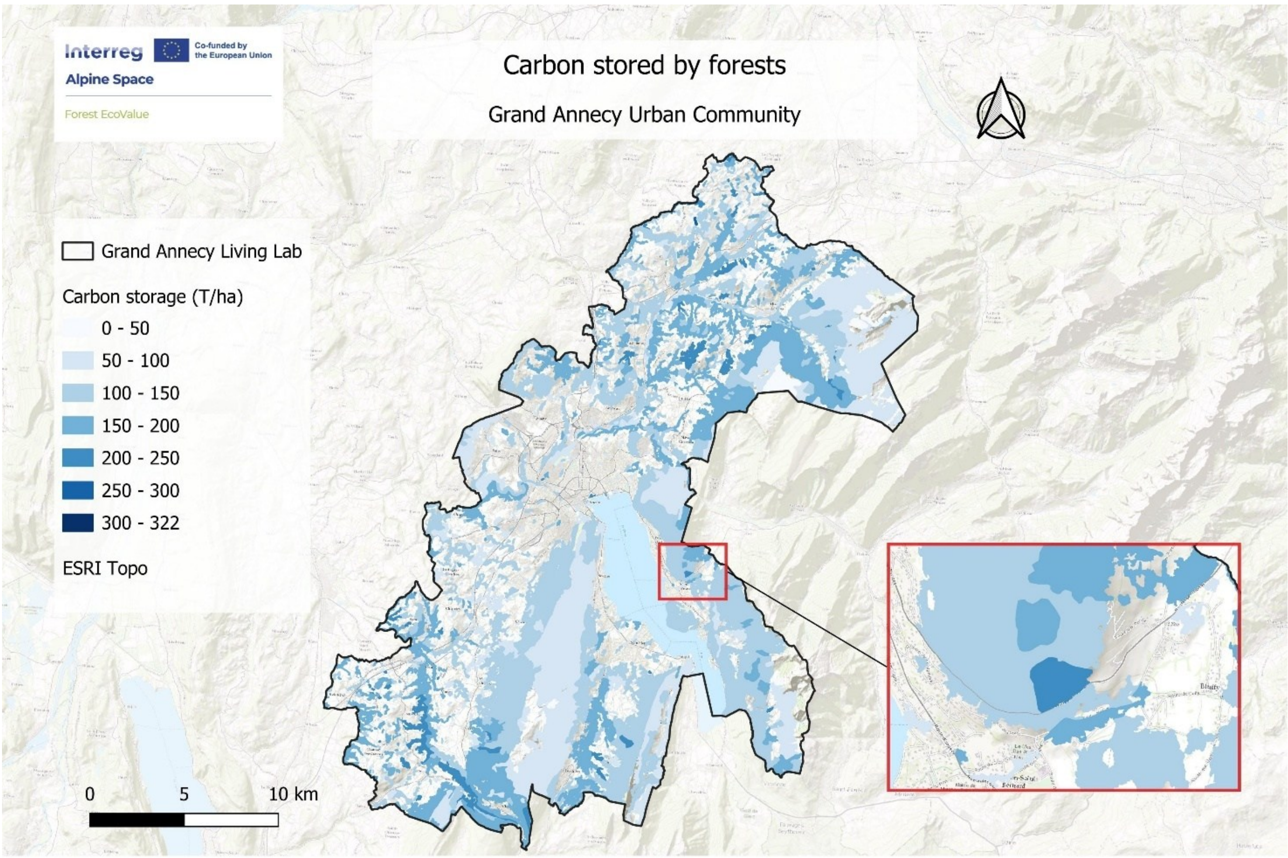
- FES 2: map of volume standing timber (production service)



Sources :
IFN : stands ; LIDAR HD ONF : Dendrometry

Production : INRAE, Nov 2025

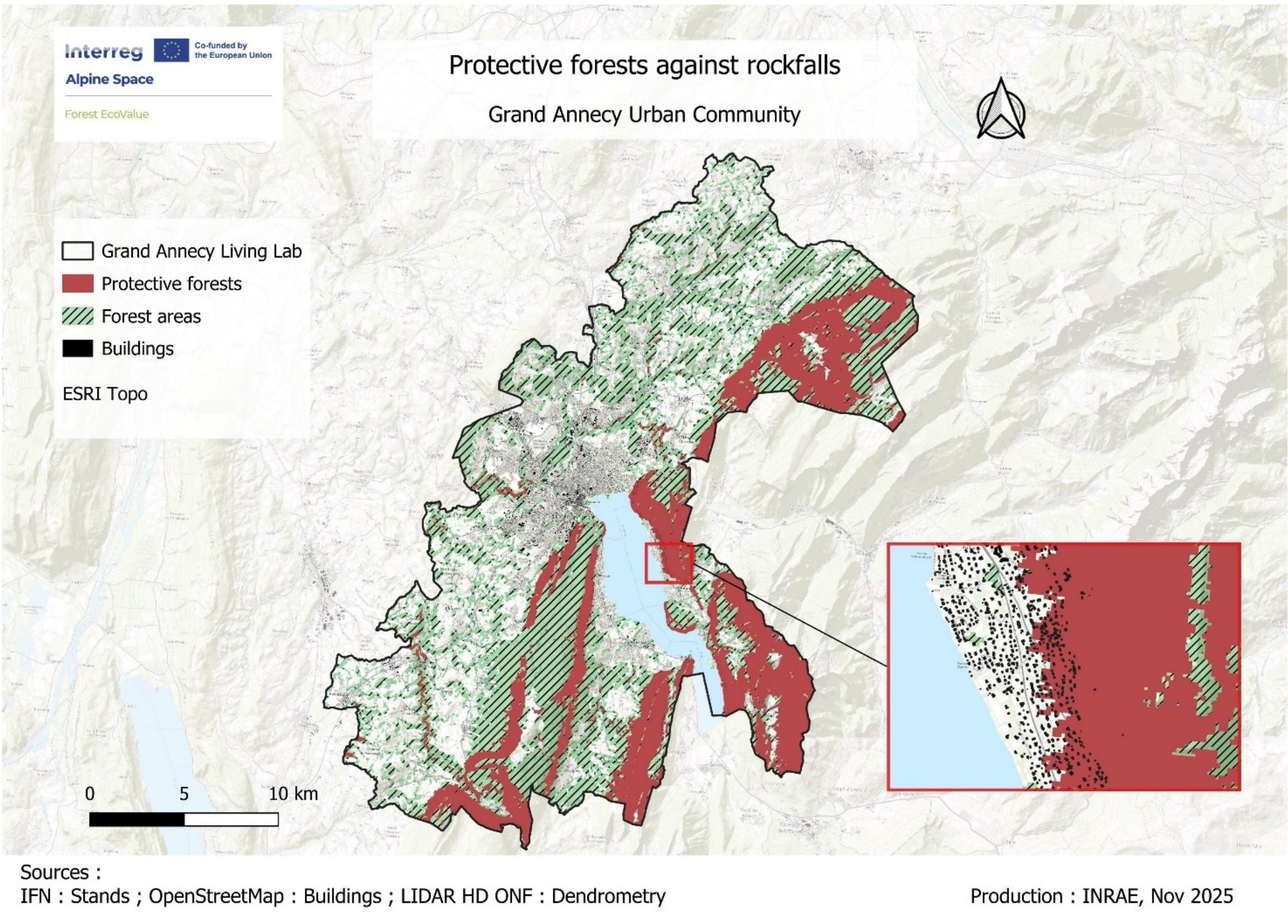
- FES3: map of carbon storage in forest areas (regulation service)



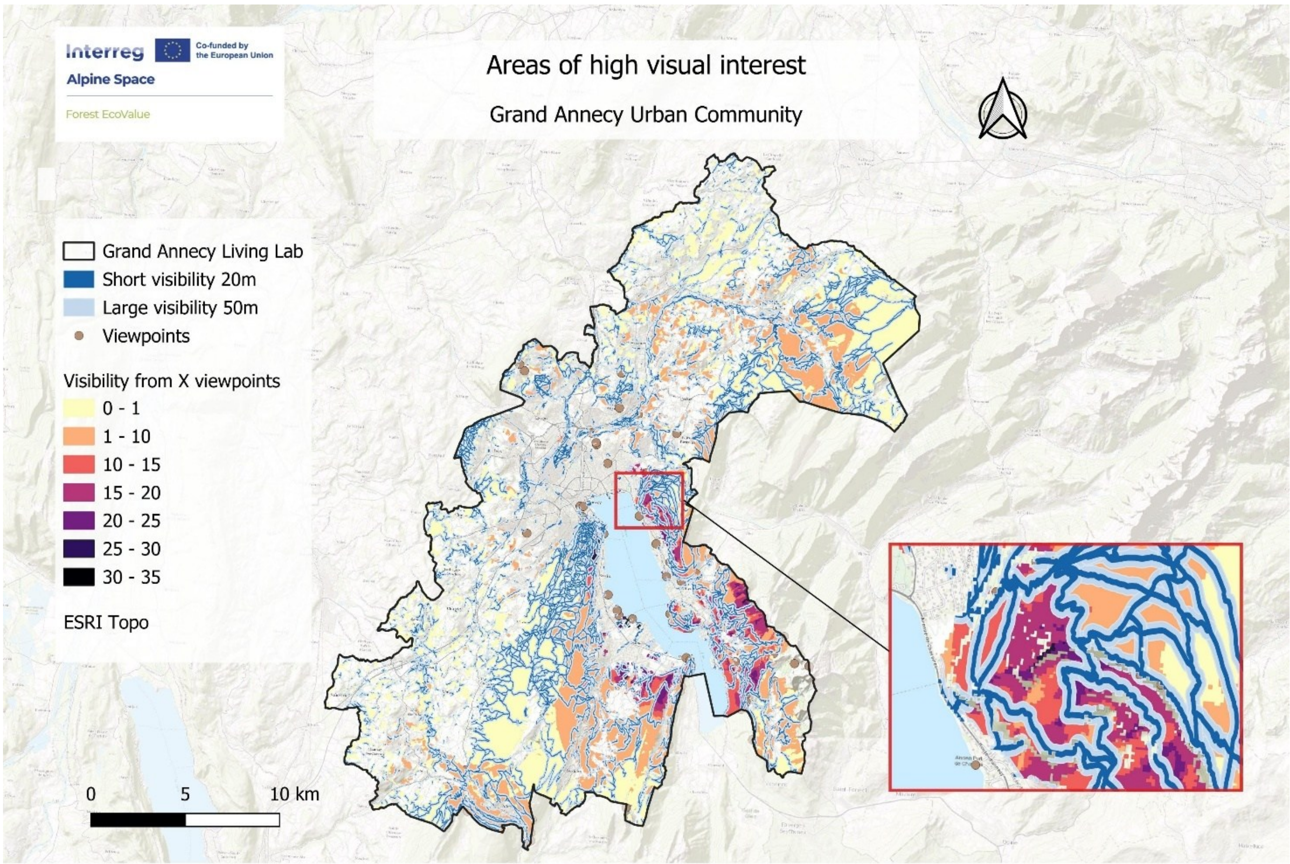
Sources :
IFN : stands ; LIDAR HD ONF : Dendrometry

Production : INRAE, Nov 2025

- FES4: map of protective forest against rockfall risks (regulation service)

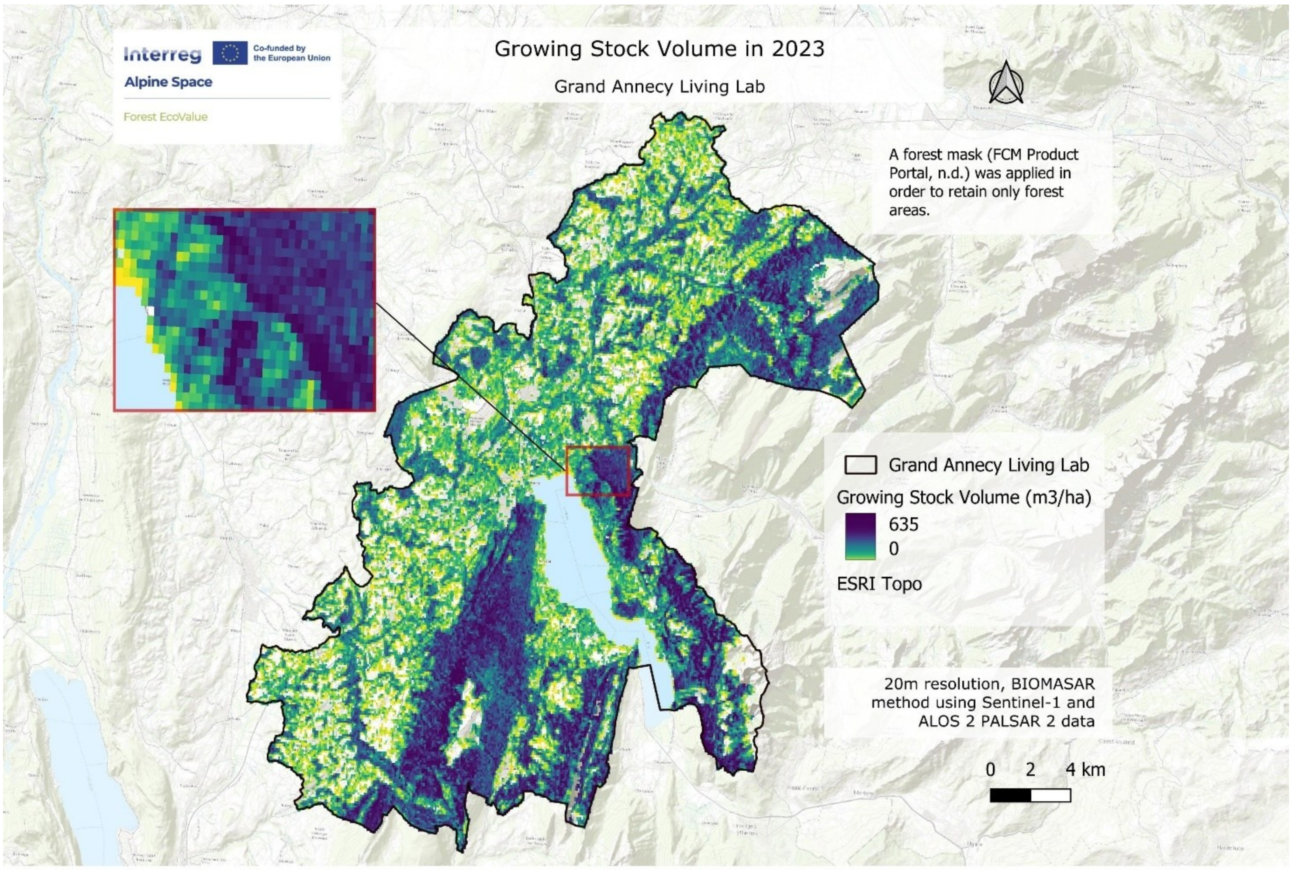


- FES 5: map of high visual interest (cultural service)



Sources : IFN : stands ; OpenStreetMap : traffic   Production : INRAE, Nov 2025

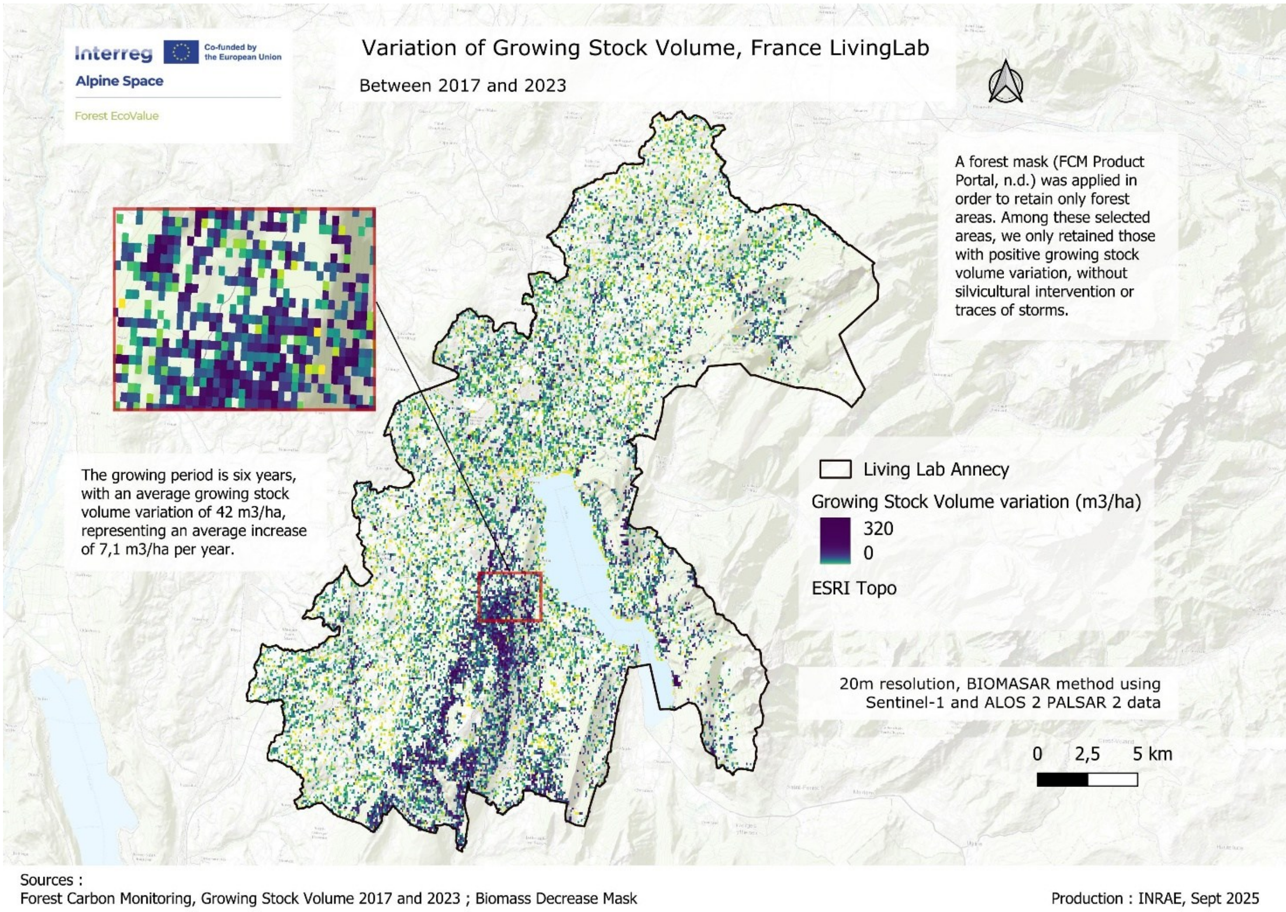
- FES 6: map of growing stock volume (regulation and support service)



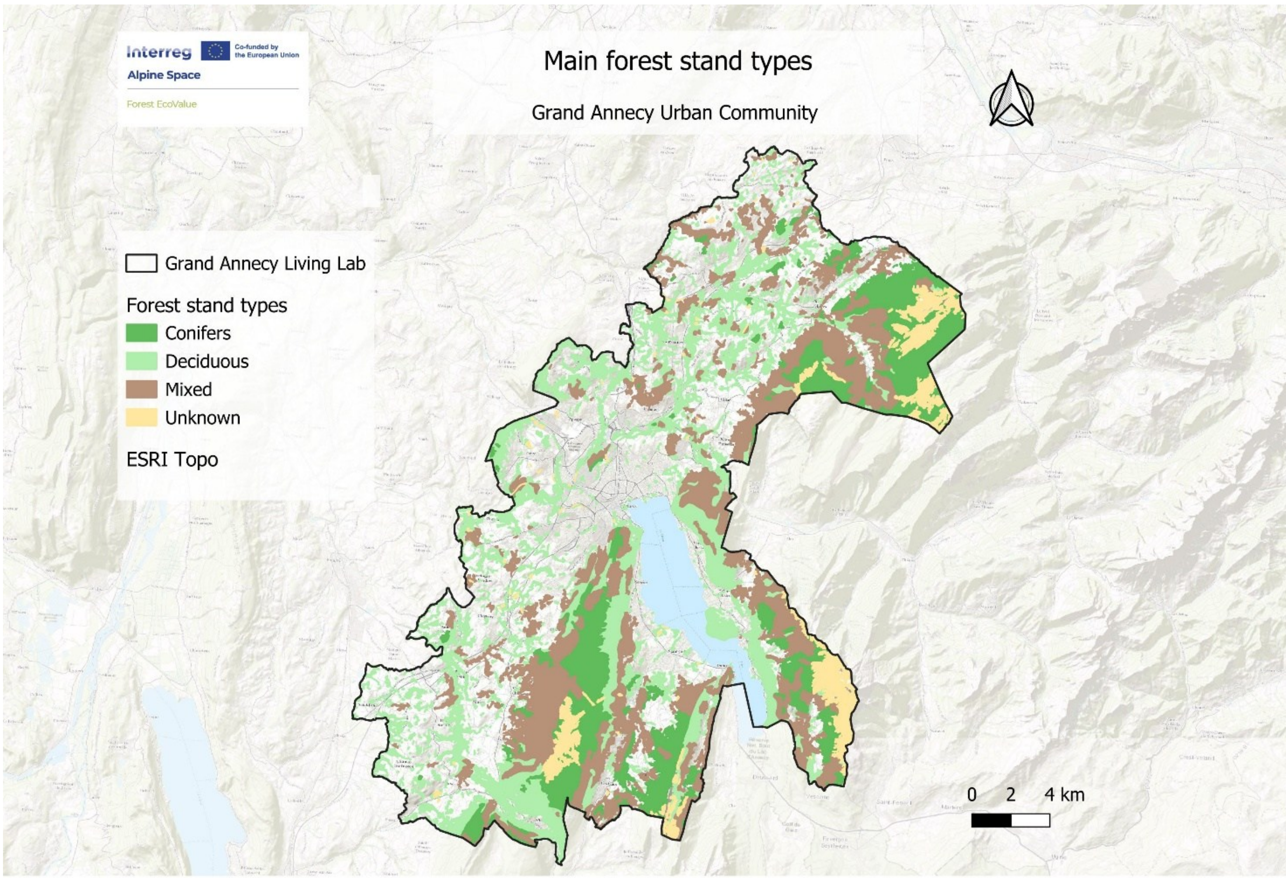
Sources :
Forest Carbon Monitoring, Growing Stock Volume 2023 ; Biomass Decrease Mask

Production : INRAE, Oct 2025

- FES 7: map of growing stock volume increment (regulation and support service)



- Map of main forest stand types (supporting all FESs biophysical assessment)



Sources : IFN (stands) ; LIDAR HD ONF (Dendrometry) Production : INRAE, Oct 2025

- *Synthesis table listing each FES with its associated indicator and value*

	Deciduous	**Coniferous**	**Mixed**
Area total (ha)	9024,22	6611,83	8680,95
mean Carbon stored (T/ha)	118,51	88,06	113,97
Total Carbon stored (T)	1069503,20	582224,99	989327,71
mean Volume (m^3/ha)	325,3423	357,0051	376,6796
Total Volume (m^3)	2935961,79	2360458,10	3269936,02
mean Growth (m^3/ha.year): high-range estimate	4,07692	5,997423	5,502313
mean Growth (m^3/ha.year): mid-range estimate	3,13	4,61	4,23
mean Growth (m^3/ha.year): low-range estimate	2,59	3,80	3,49
Carbon sequestration (T/year): high estimate	1,94	2,85	2,61
Carbon sequestration (T/year): mid-range estimate	1,49	2,19	2,01
Carbon sequestration (T/year): low-range estimate	1,23	1,81	1,66
% of forest stands	37,11%	27,19%	35,70%

	Biodiversity	**Production**	**Protective**	**Tourism**
Area total (ha)	1299,60	26208,82	8678,05	22945,33
mean Carbon stored (T/ha)	135,33	116,53	105,09	122,06
mean Volume (m^3/ha)	408,24	378,24	346,84	397,35
mean Growth (m^3/ha.year): high-range estimate	5,29	6,53	7,86	6,38
mean Growth (m^3/ha.year): mid-range estimate	4,06	5,02	6,04	4,90
mean Growth (m^3/ha.year): low-range estimate	3,36	4,14	4,99	4,05
Carbon sequestration (T/ha.year): high-range estimate	2,51	3,10	3,73	3,03
Carbon sequestration (T/year): mid-range estimate	1,93	2,38	2,87	2,33
Carbon sequestration (T/ha.year): low-range estimate	1,59	1,97	2,37	1,92
FES in % of the total forest area	4,96%	100,00%	33,11%	87,55%

BIODIVERSITE	Deciduous	Coniferous	Mixed
Area total (ha)	*746,74*	*120,08*	*32,33*
mean Carbon stored (T/ha)	146,63	106,66	133,95
Total Carbon stored (T)	109494,06	12808,24	4331,12
mean Volume (m^3/ha)	402,70	444,75	444,62
Total Volume (m^3)	300716,14	53406,63	14376,39
mean Growth (m^3/ha.year): high-range estimate	5,26	5,81	5,04
mean Growth (m^3/ha.year): mid-range estimate	4,04	4,46	3,87
mean Growth (m^3/ha.year): low estimate	3,34	3,69	3,19
Carbon sequestration (T/ha.year): high-range estimate	2,50	2,76	2,39
Carbon sequestration (T/year): mid-range estimate	1,92	2,12	1,84
Carbon sequestration (T/ha.year): low-range estimate	1,58	1,75	1,52
% of forest stands	83,05%	13,36%	3,60%

PRODUCTION	Deciduous	Coniferous	Mixed
Area total (ha)	*8944,33*	*6320,37*	*8546,00*
mean Carbon stored (T/ha)	143,61	98,03	130,58
Total Carbon stored (T)	1284527,35	619572,79	1115949,10
mean Volume (m^3/ha)	394,76	405,86	433,06
Total Volume (m^3)	3530842,40	2565208,18	3700942,03
mean Growth (m^3/ha.year): high-range estimate	6,65	7,27	7,12
mean Growth (m^3/ha.year): mid-range estimate	5,11	5,58	5,47
mean Growth (m^3/ha.year): low estimate	4,22	4,61	4,52
Carbon sequestration (T/ha.year): high-range estimate	3,16	3,45	3,38
Carbon sequestration (T/year): mid-range estimate	2,43	2,65	2,60
Carbon sequestration (T/ha.year): low-range estimate	2,00	2,19	2,15
% of forest stands	37,56%	26,54%	35,89%

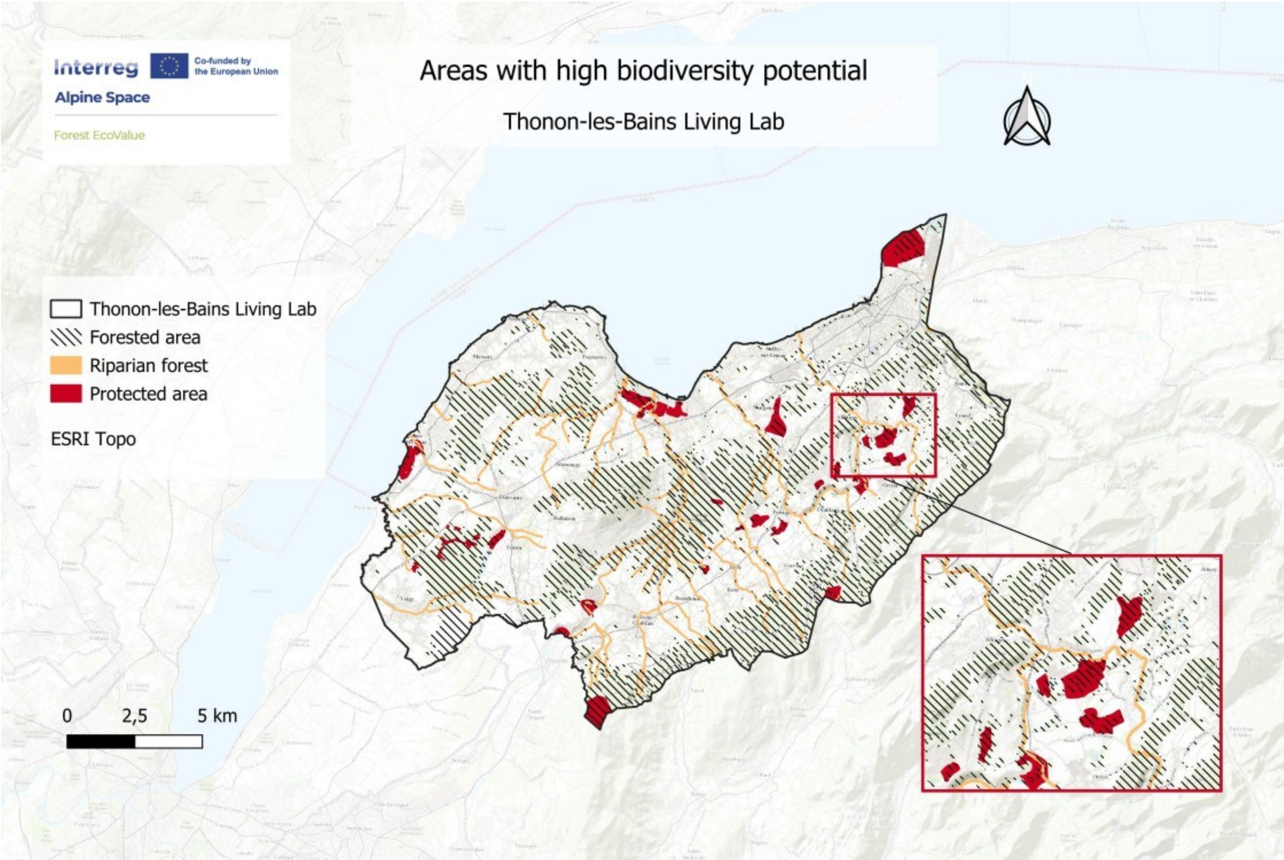
PROTECTIVE	Deciduous	Coniferous	Mixed
Area total (ha)	*2287,12*	*1776,17*	*3053,67*
mean Carbon (T/ha)	135,69	105,31	135,77
Total Carbon (T)	310345,20	187055,79	414603,24
mean Volume (m^3/ha)	373,75	438,71	450,57
Total Volume (m^3)	854814,93	779220,31	1375878,67
mean Growth (m^3/ha.year): high-range estimate	9,39	5,70	7,68
mean Growth (m^3/ha.year): mid-range estimate	7,21	4,37	5,90
mean Growth (m^3/ha.year): low estimate	5,96	3,61	4,87
Carbon sequestration (T/ha.year): high-range estimate	4,46	2,71	3,65
Carbon sequestration (T/year): mid-range estimate	3,43	2,08	2,80
Carbon sequestration (T/ha.year): low-range estimate	2,83	1,72	2,32
% of forest stands	32,14%	24,96%	42,91%

PROTECTIVE	Deciduous	Coniferous	Mixed
Area total (ha)	*2287,12*	*1776,17*	*3053,67*
mean Carbon (T/ha)	135,69	105,31	135,77
Total Carbon (T)	310345,20	187055,79	414603,24
mean Volume (m^3/ha)	373,75	438,71	450,57
Total Volume (m^3)	854814,93	779220,31	1375878,67
mean Growth (m^3/ha.year): high-range estimate	9,39	5,70	7,68
mean Growth (m^3/ha.year): mid-range estimate	7,21	4,37	5,90
mean Growth (m^3/ha.year): low estimate	5,96	3,61	4,87
Carbon sequestration (T/ha.year): high-range estimate	4,46	2,71	3,65
Carbon sequestration (T/year): mid-range estimate	3,43	2,08	2,80
Carbon sequestration (T/ha.year): low-range estimate	2,83	1,72	2,32
% of forest stands	32,14%	24,96%	42,91%

Total road length within the living lab area (km)	2694,7
Road length protected by protection forests (km)	82,2
Percentage of roads protected by forest (%)	3,05%
Total number of buildings protected by protection forest	1648

5.2LL1b: Thonon Agglomération

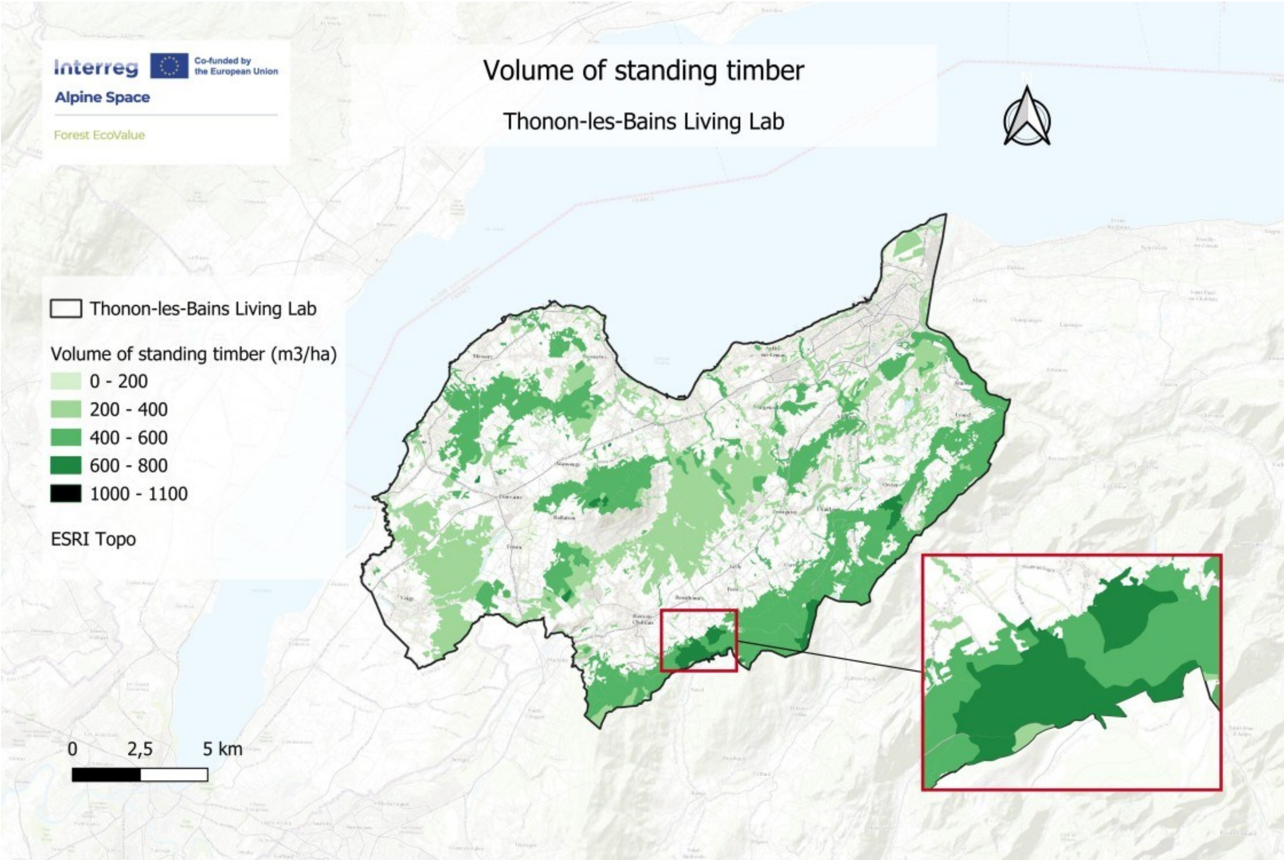
- FES1: map of forest areas with high biodiversity and habitat support potential (support service)



Sources :
Forest : IFN ; Dendrometry : LIDAR HD ONF

Production : INRAE, Oct 2025

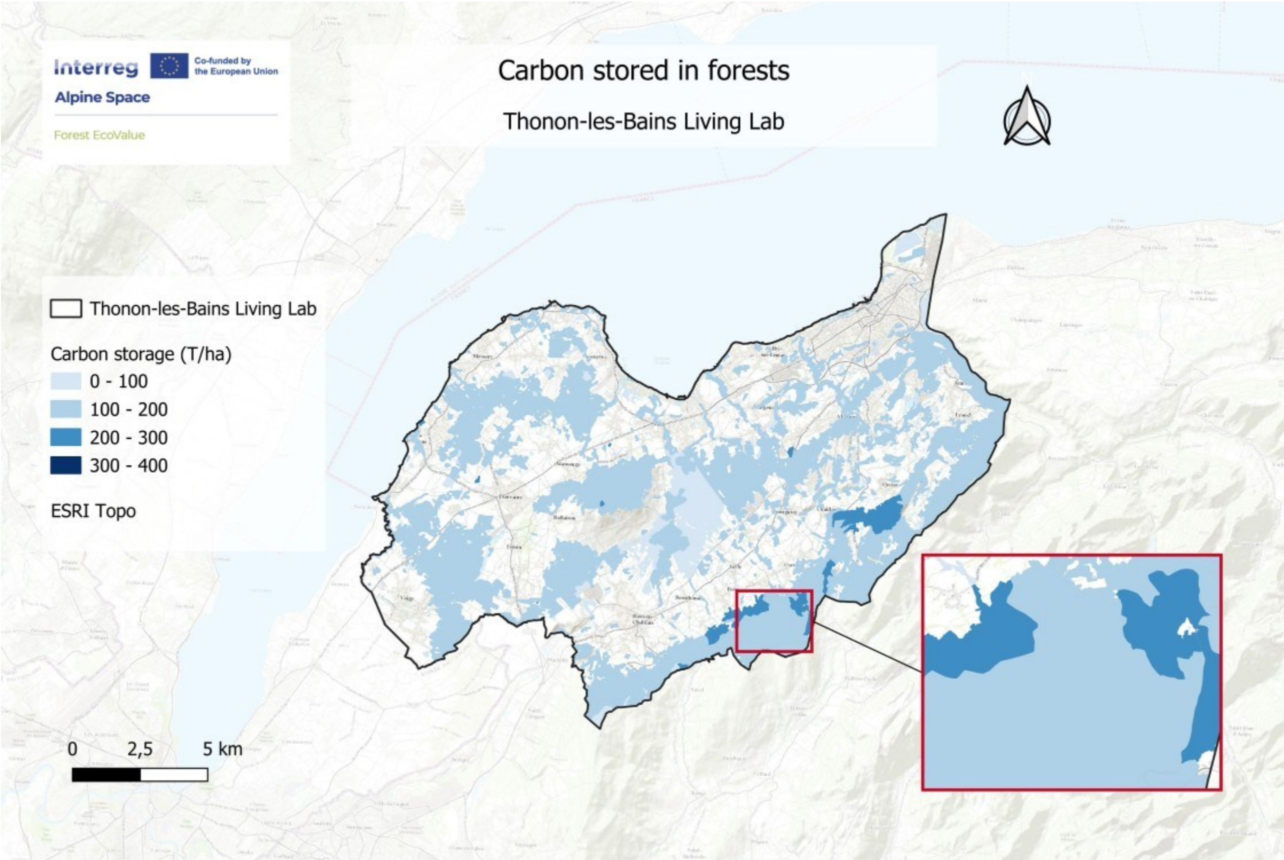
- FES 2: map of volume standing timber (timber production service)



Sources :
Timber volume : IFN

Production : INRAE, Oct 2025

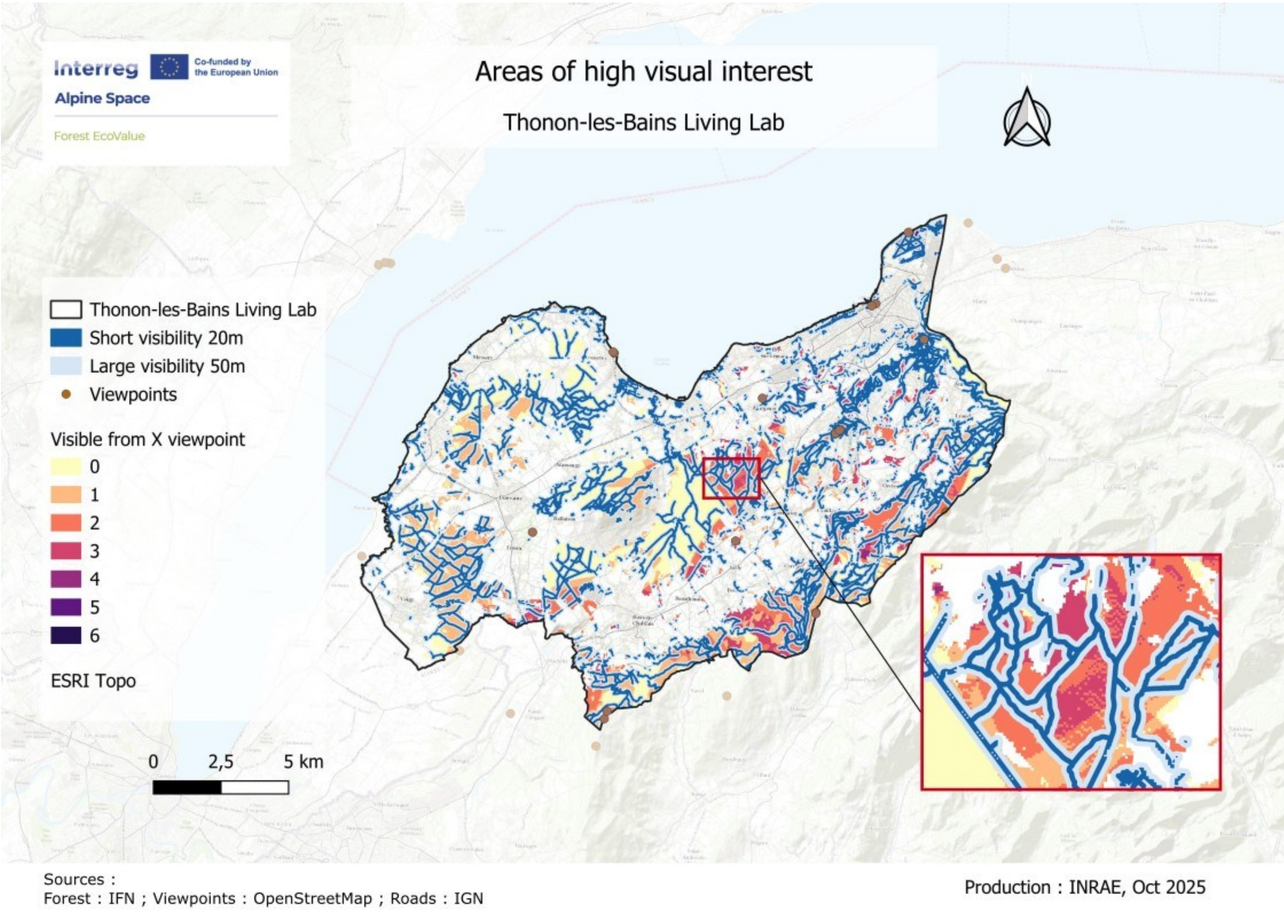
- FES3: map of carbon storage in forest areas (regulation service)



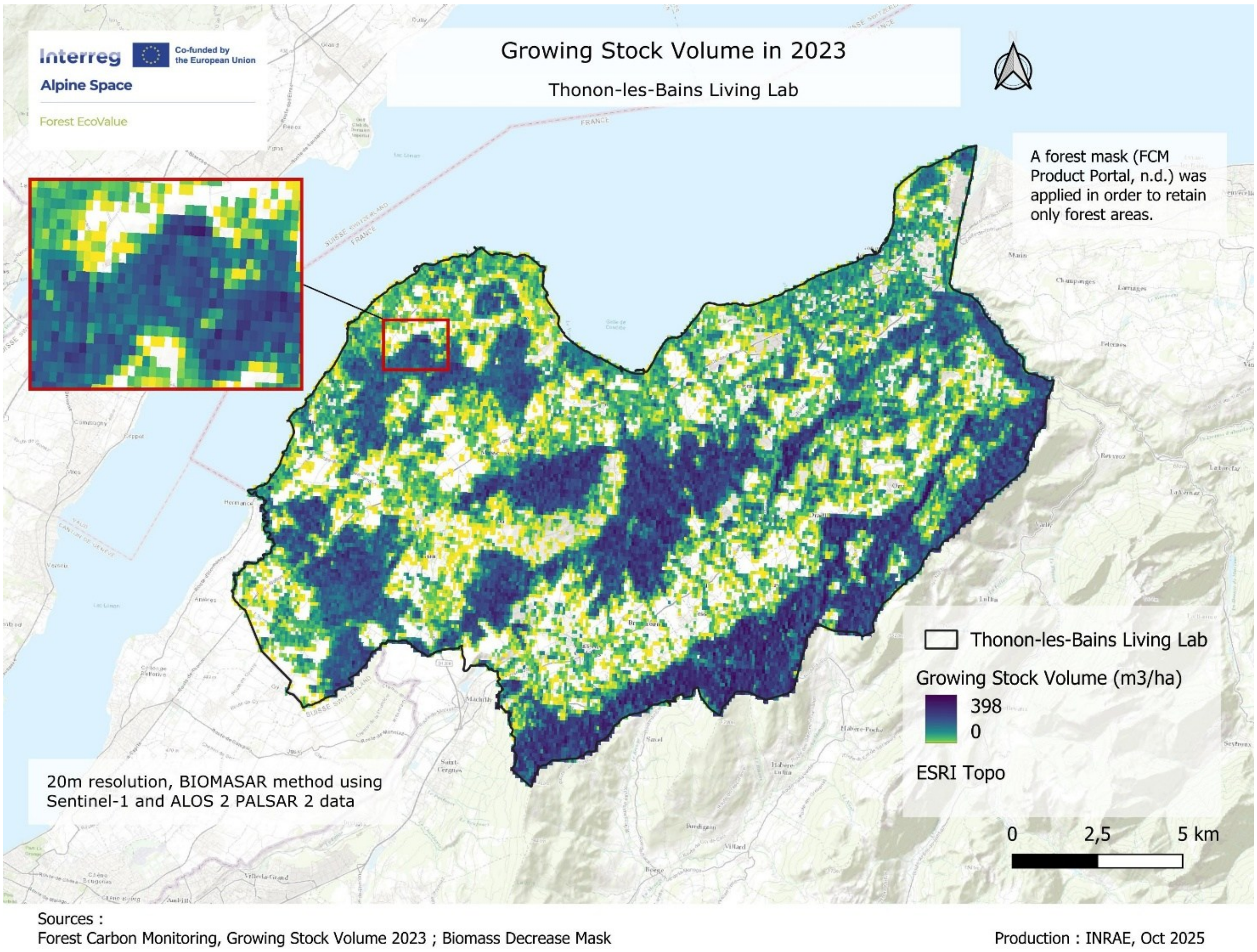
Sources :
Forest : IFN ; Dendrometry : LIDAR HD ONF

Production : INRAE, Oct 2025

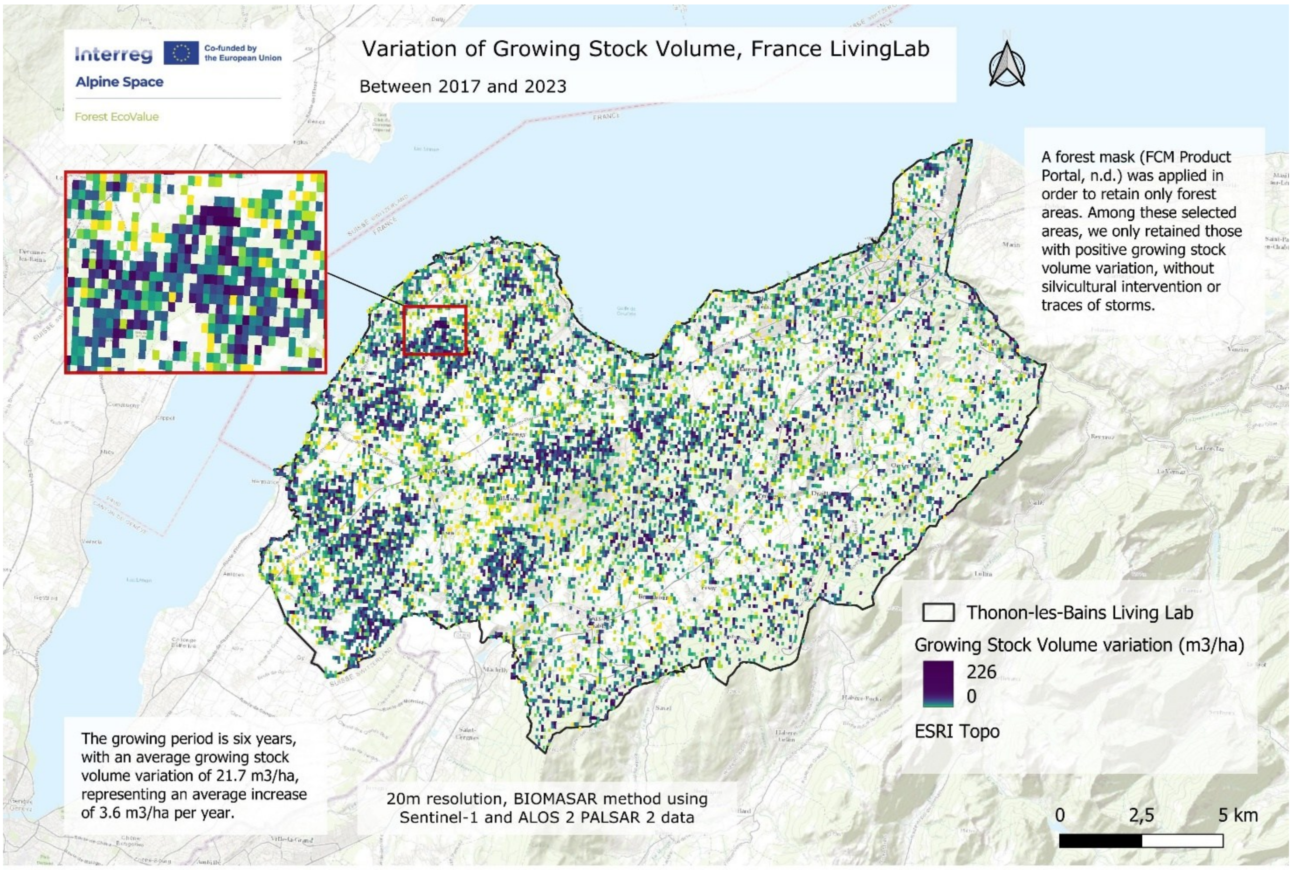
- FES 4: map of high visual interest (cultural service)



- FES 6: map of growing stock volume (regulation and support service)



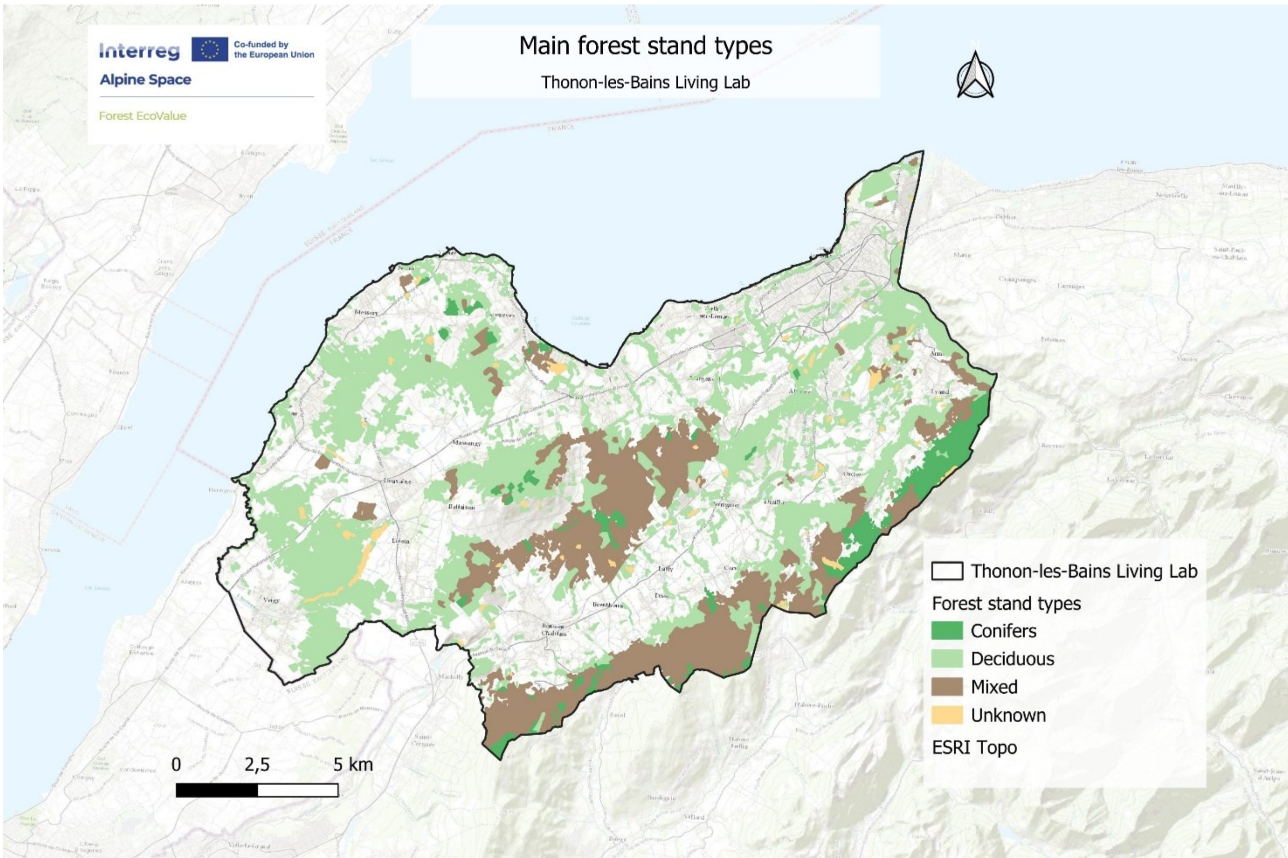
- FES 7: map of growing stock volume increment (regulation and support service)
-



Sources :
Forest Carbon Monitoring, Growing Stock Volume 2017 and 2023 ; Biomass Decrease Mask

Production : INRAE, Sept 2025

- Map of main forest stand types (supporting all FESs biophysical assessment)



Sources : IFN (stands) ; LIDAR HD ONF (Dendrometry) Production : INRAE, Oct 2025

- *Synthesis table listing each FES with its associated indicator and value*

	Deciduous	**Coniferous**	**Mixed**
Area total (ha)	5830,61	742,67	2977,71
mean Carbon stored (T/ha)	110,94	109,25	119,84
Total Carbon stored (T)	646828,38	81140,08	356833,64
mean Volume (m^3/ha)	303,8743	433,311	397,1185
Total Volume (m^3)	1771773,44	321806,95	1182502,93
mean Growth (m^3/ha.year): high-range estimate	3,294701	4,731399	4,34326
mean Growth (m^3/ha.year): mid-range estimate	2,53	3,63	3,34
mean Growth (m^3/ha.year): low-range estimate	2,09	3,00	2,75
Carbon sequestration (T/year): high estimate	1,56	2,25	2,06
Carbon sequestration (T/year): mid-range estimate	1,20	1,73	1,58
Carbon sequestration (T/year): low-range estimate	0,99	1,43	1,31
% of forest stands	61,05%	7,78%	31,18%

	Biodiversity	**Production**	**Protective**	**Tourism**
Area total (ha)	1333,36	9696,21	0,00	9409,60
mean Carbon stored (T/ha)	68,49	136,03	0,00	137,57
mean Volume (m^3/ha)	202,99	408,44	0,00	413,42
mean Growth (m^3/ha.year): high-range estimate	3,52	4,76	0,00	4,91
mean Growth (m^3/ha.year): mid-range estimate	2,70	3,66	0,00	3,77
mean Growth (m^3/ha.year): low-range estimate	2,23	3,02	0,00	3,12
Carbon sequestration (T/ha.year): high-range estimate	1,67	2,26	0,00	2,33
Carbon sequestration (T/year): mid-range estimate	1,28	1,74	0,00	1,79
Carbon sequestration (T/ha.year) : low-range estimate	1,06	1,44	0,00	1,48
FES in % of the total forest area	13,75%	100,00%	0,00%	97,04%

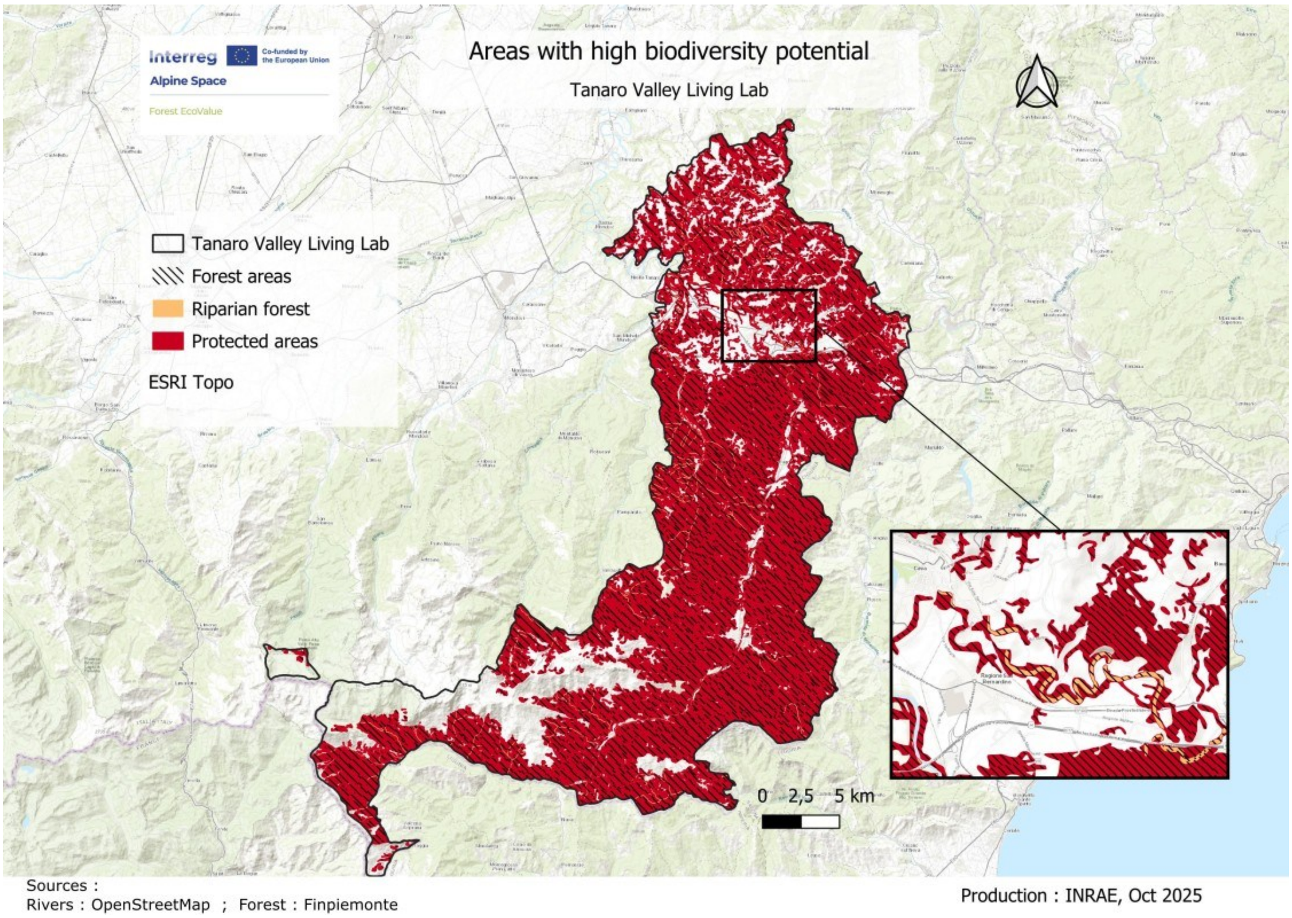
BIODIVERSITE	Deciduous	Coniferous	Mixed
Area total (ha)	*491,34*	*35,77*	*223,88*
mean Carbon stored (T/ha)	123,72	94,54	121,27
Total Carbon stored (T)	60790,93	3381,46	27150,88
mean Volume (m^3/ha)	338,90	394,84	402,11
Total Volume (m^3)	166517,64	14121,82	90025,50
mean Growth (m^3/ha.year): high-range estimate	3,90	4,26	5,20
mean Growth (m^3/ha.year): mid-range estimate	3,00	3,27	3,99
mean Growth (m^3/ha.year): low estimate	2,48	2,70	3,30
Carbon sequestration (T/ha.year): high-range estimate	1,85	2,02	2,47
Carbon sequestration (T/year): mid-range estimate	1,42	1,55	1,90
Carbon sequestration (T/ha.year): low-range estimate	1,18	1,28	1,57
% of forest stands	65,43%	4,76%	29,81%

PRODUCTION	Deciduous	Coniferous	Mixed
Area total (ha)	*5794,35*	*695,59*	*2969,63*
mean Carbon stored (T/ha)	144,27	116,34	131,86
Total Carbon stored (T)	835960,86	80924,34	391578,93
mean Volume (m^3/ha)	394,35	485,15	437,94
Total Volume (m^3)	2285009,07	337464,95	1300506,34
mean Growth (m^3/ha.year): high-range estimate	4,73	5,24	4,89
mean Growth (m^3/ha.year): mid-range estimate	3,63	4,02	3,76
mean Growth (m^3/ha.year): low estimate	3,00	3,32	3,10
Carbon sequestration (T/ha.year): high-range estimate	2,25	2,49	2,32
Carbon sequestration (T/year): mid-range estimate	1,72	1,91	1,78
Carbon sequestration (T/ha.year): low-range estimate	1,42	1,58	1,47
% of forest stands	61,25%	7,35%	31,39%

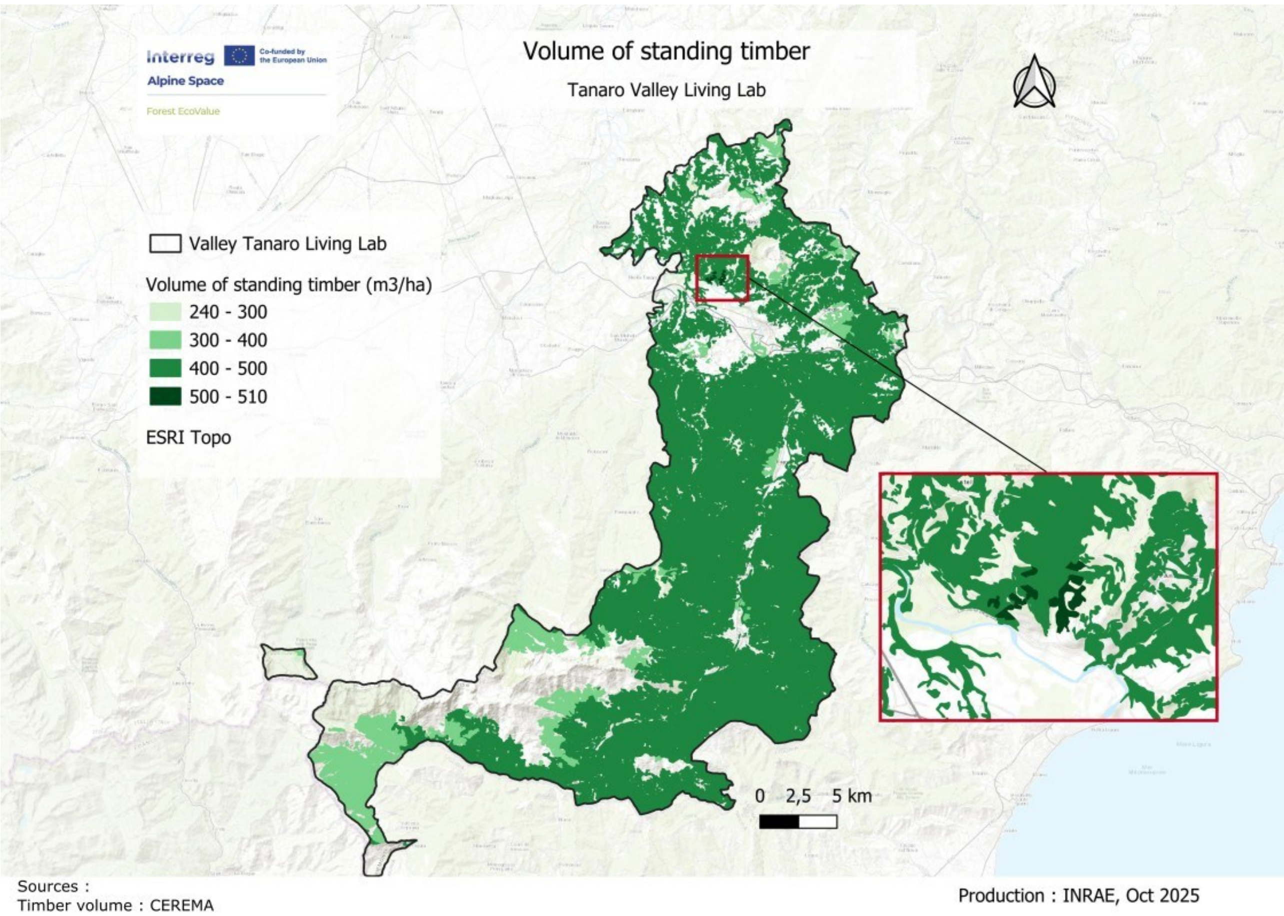
TOURISM	Deciduous	Coniferous	Mixed
Area total (ha)	*5678,42*	*719,90*	*2948,44*
mean Carbon (T/ha)	144,28	116,76	131,77
Total Carbon (T)	819277,11	84055,86	388530,65
mean Volume (m^3/ha)	394,36	486,82	437,65
Total Volume (m^3)	2239330,89	350459,88	1290381,59
mean Growth (m^3/ha.year): high-range estimate	4,88	5,01	4,97
mean Growth (m^3/ha.year): mid-range estimate	3,75	3,85	3,82
mean Growth (m^3/ha.year): low estimate	3,09	3,18	3,16
Carbon sequestration (T/ha.year): high-range estimate	2,32	2,38	2,36
Carbon sequestration (T/year): mid-range estimate	1,78	1,83	1,81
Carbon sequestration (T/ha.year): low-range estimate	1,47	1,51	1,50
% of forest stands	60,75%	7,70%	31,55%

5.3LL2: Alta Valle Tanaro LL, Piedmont.

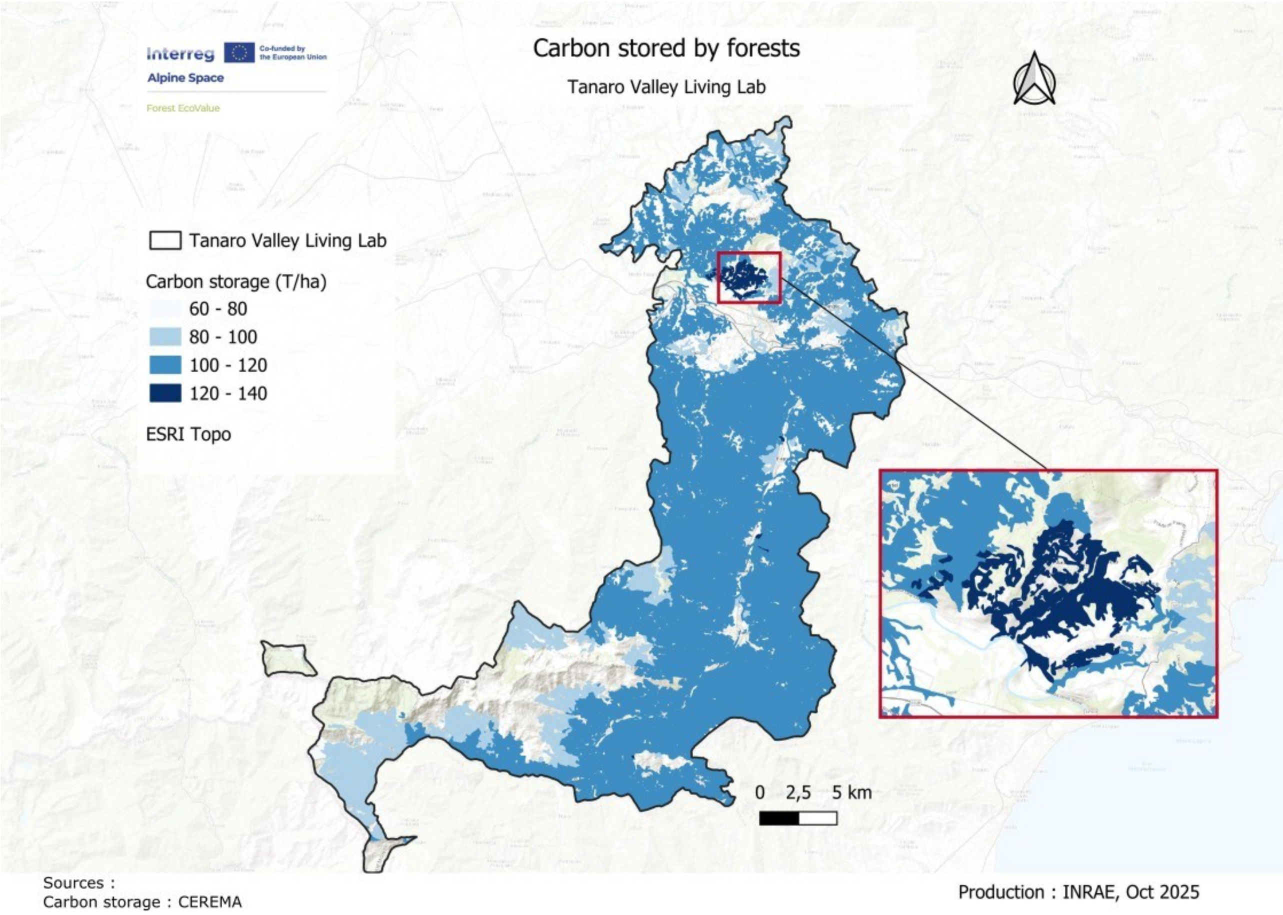
- FES1: map of forest areas with high biodiversity and habitat support potential (support service)



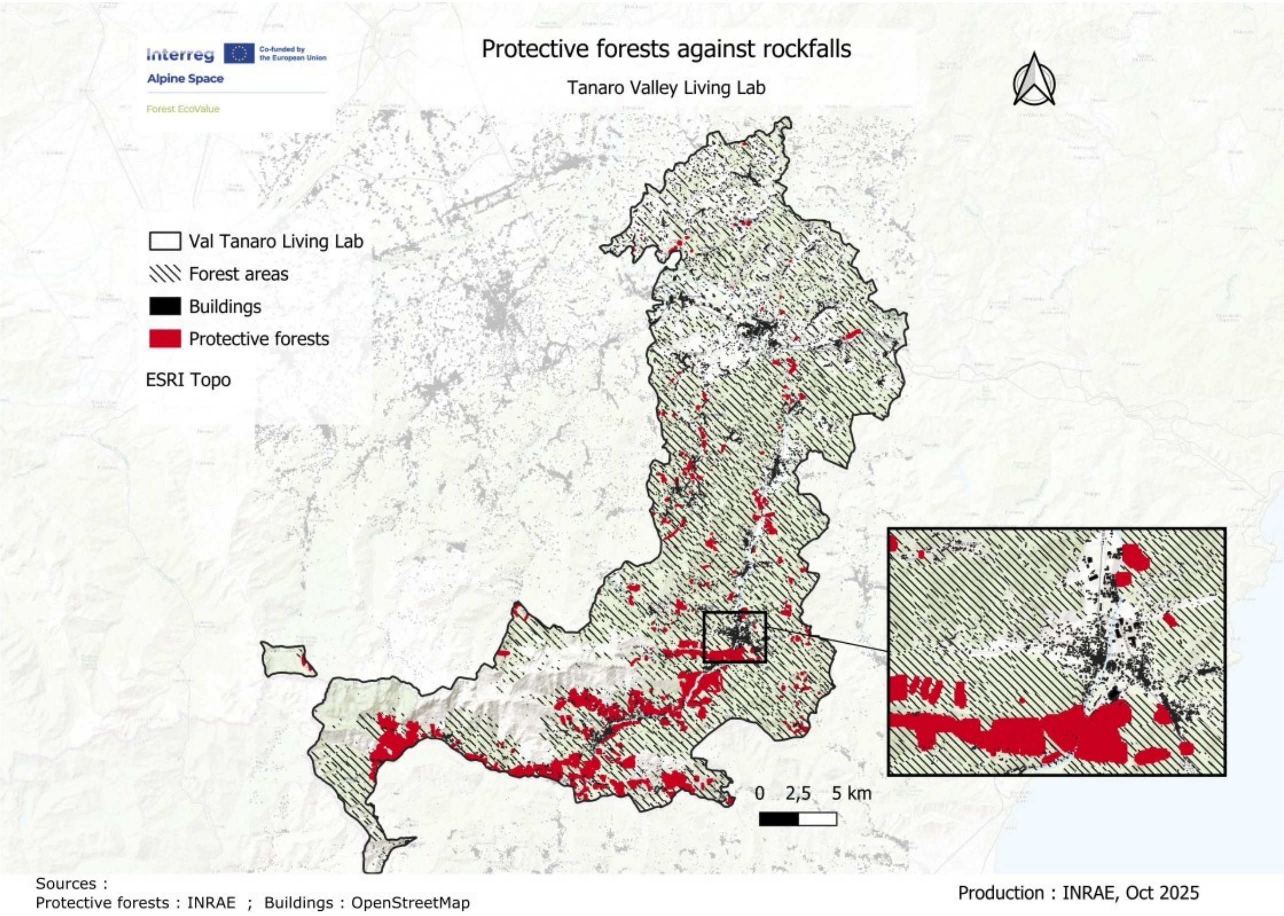
- FES 2: map of volume standing timber (timber production service)



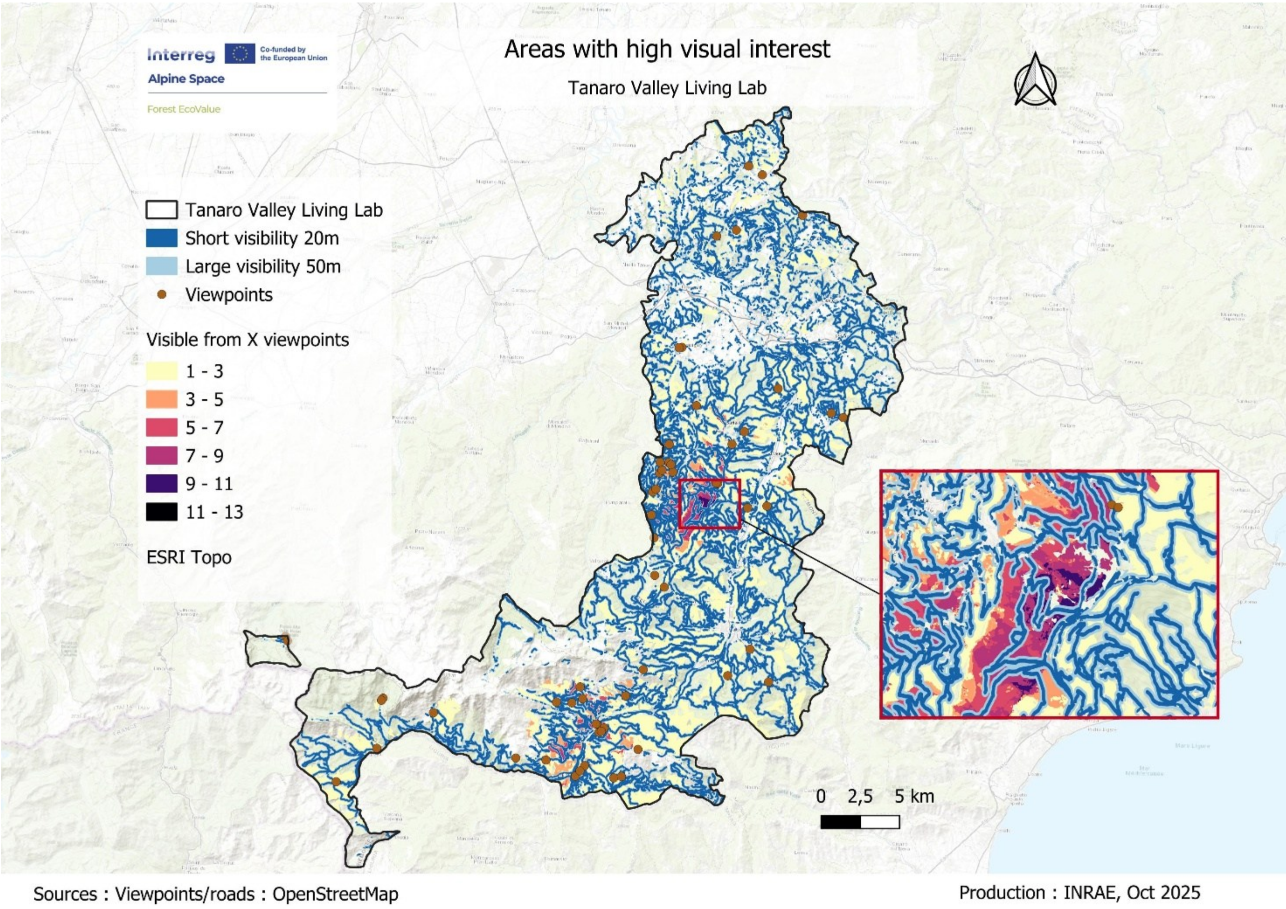
- FES3: map of carbon storage in forest areas (regulation service)



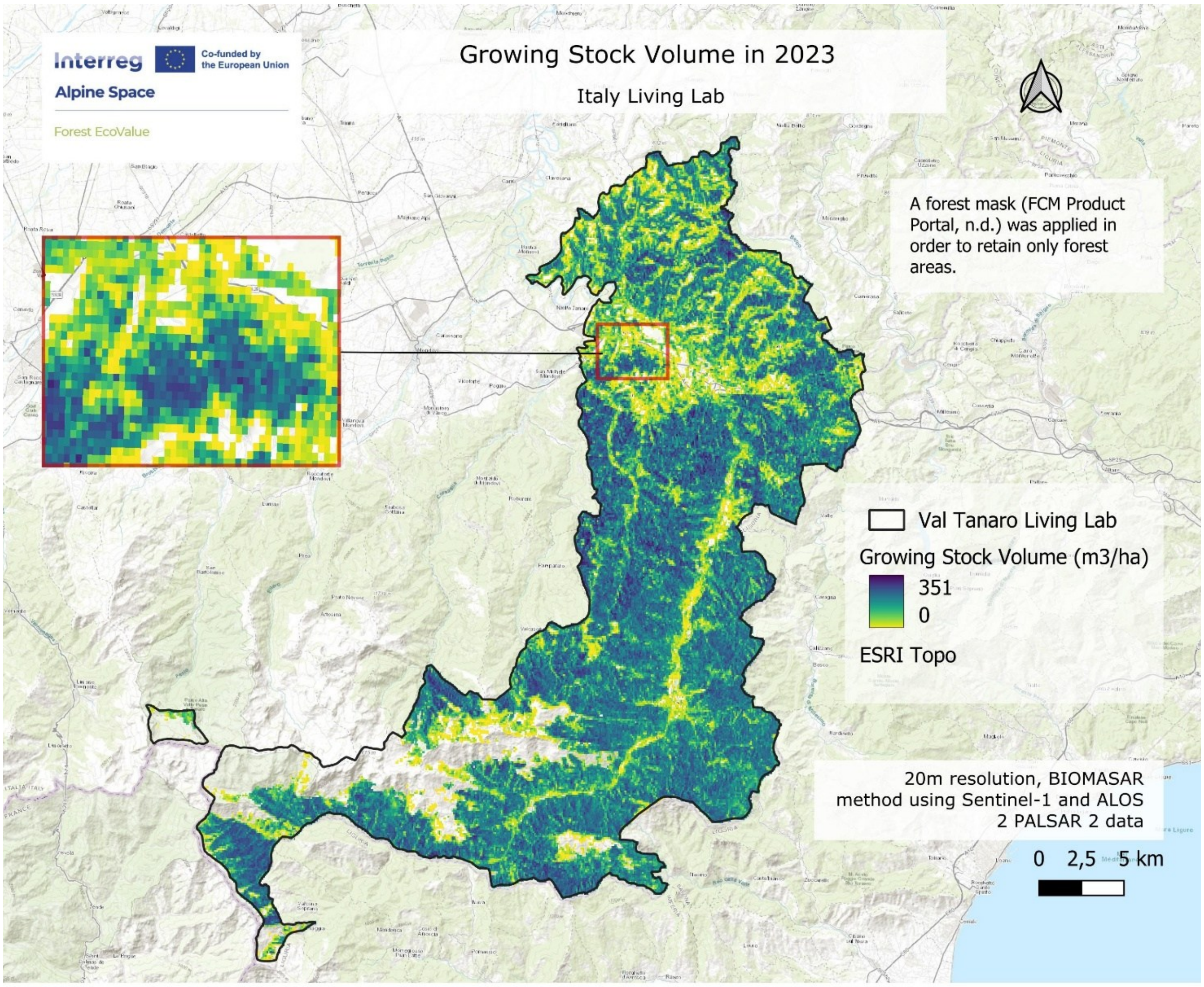
- FES4: map of protective forest against rockfall risks (regulation service)



- FES 5: map of high visual interest (cultural service)

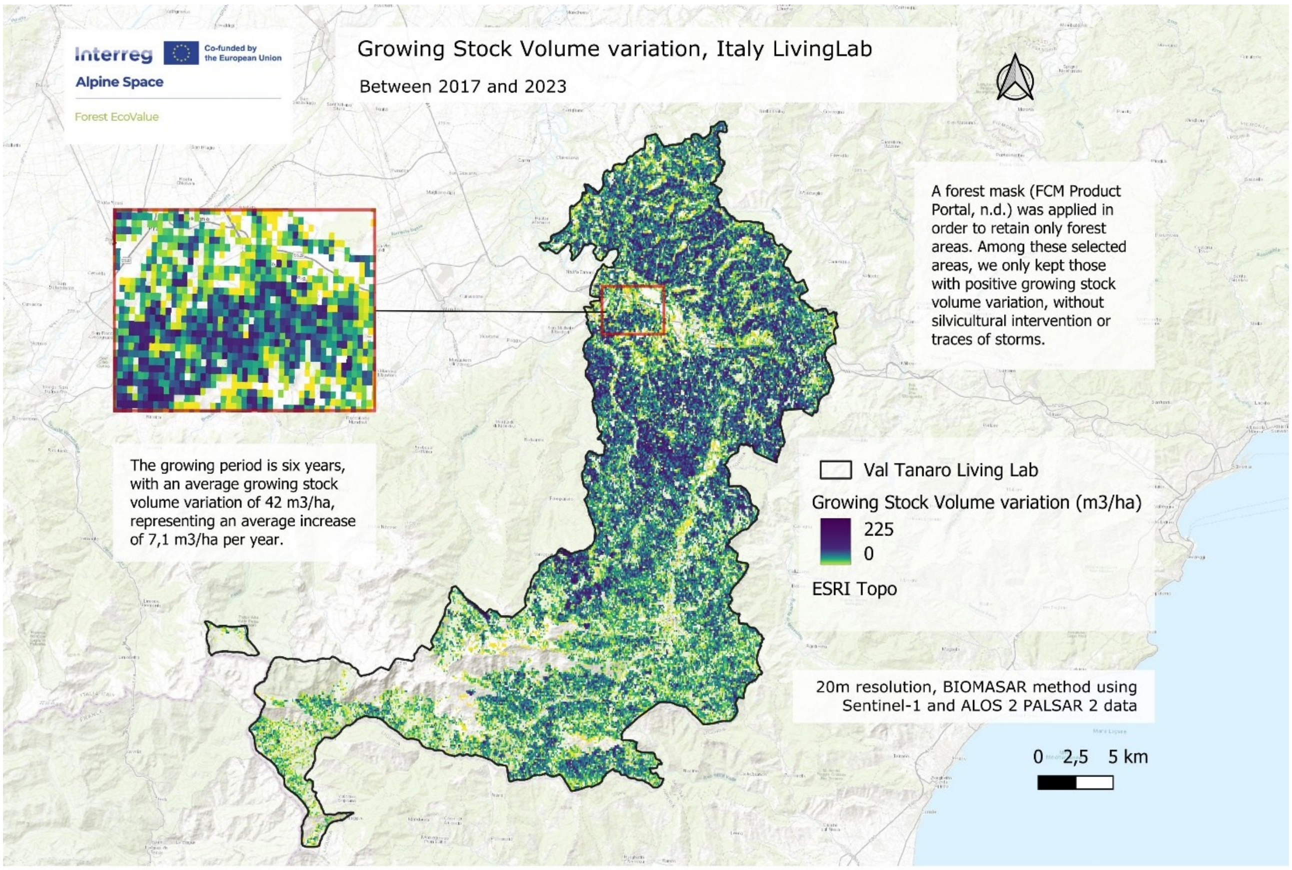


- FES 6: map of growing stock volume (regulation and support service)



Sources : Forest Carbon Monitoring, Growing Stock 2023 ; Biomass Decrease Mask Production : INRAE, Sept 2025

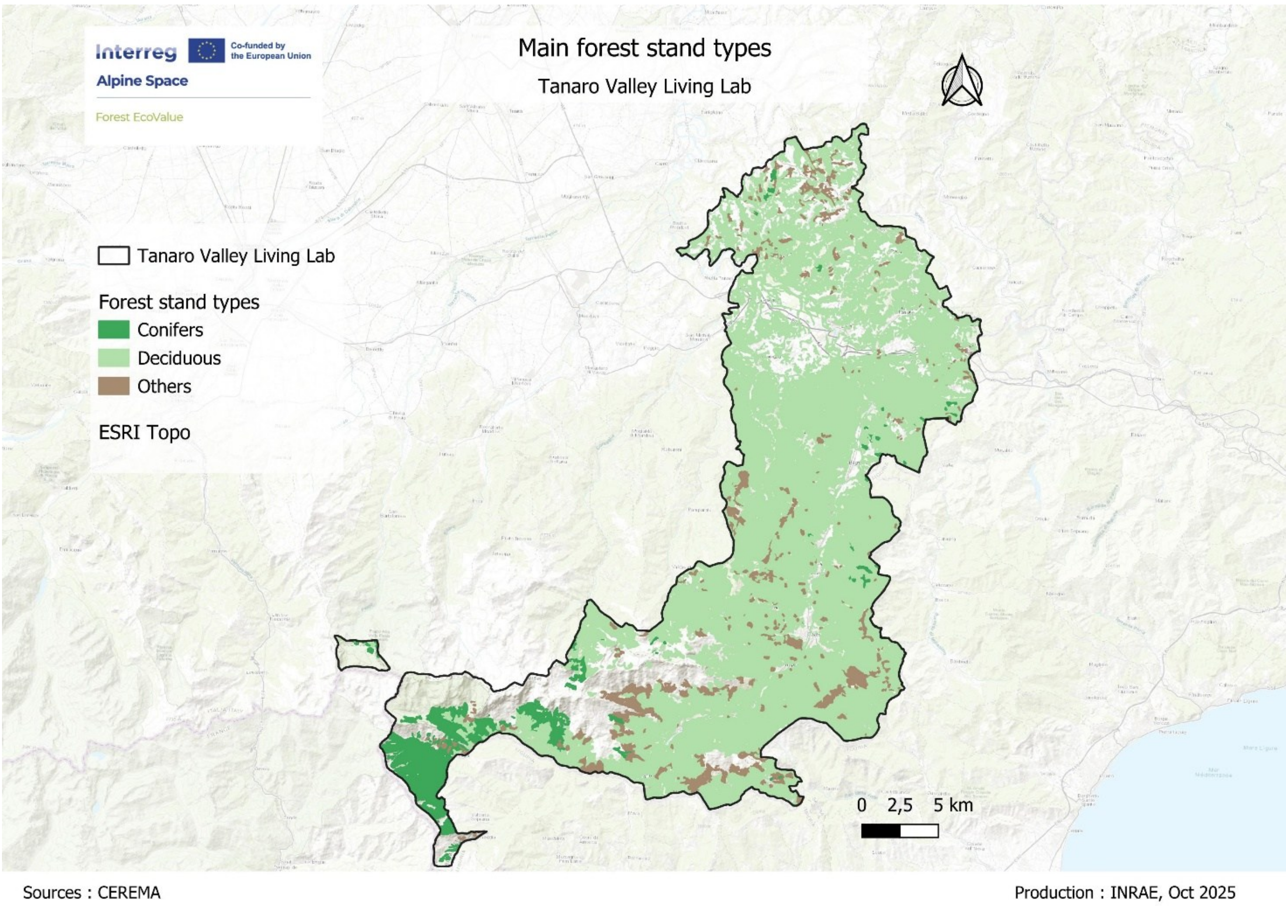
- FES 7: map of growing stock volume increment (regulation and support service)



Sources :
Forest Carbon Monitoring, Growing Stock Volume 2017 and 2023 ; Biomass Decrease Mask

Production : INRAE, Sept 2025

- Map of main forest stand types (supporting all FESs biophysical assessment)



- *Synthesis table listing each FES with its associated indicator and value*

	Deciduous	**Coniferous**	**Mixed**
Area total (ha)	37872,51	2709,53	2773,84
mean Carbon stored (T/ha)	105,94	92,66	105,00
Total Carbon stored (T)	4012213,71	251059,79	291242,14
mean Volume (m^3/ha)	429,4023	375,5679	425,5757
Total Volume (m^3)	16262542,90	1017610,61	1180480,18
mean Growth (m^3/ha.year): high-range estimate	7,501418	4,031248	6,548937
mean Growth (m^3/ha.year): mid-range estimate	5,76	3,10	5,03
mean Growth (m^3/ha.year): low-range estimate	4,76	2,56	4,15
Carbon sequestration (T/year): high estimate	3,56	1,91	3,11
Carbon sequestration (T/year): mid-range estimate	2,74	1,47	2,39
Carbon sequestration (T/year): low-range estimate	2,26	1,21	1,97
% of forest stands	87,35%	6,25%	6,40%

	Biodiversity	**Production**	**Protective**	**Tourism**
Area total (ha)	43355,88	43355,88	6796,12	19879,04
mean Carbon stored (T/ha)	101,78	101,78	48,54	102,84
mean Volume (m^3/ha)	412,56	412,56	196,73	416,83
mean Growth (m^3/ha.year): high-range estimate	7,27	7,27	5,72	7,49
mean Growth (m^3/ha.year): mid-range estimate	5,58	5,58	4,40	5,75
mean Growth (m^3/ha.year): low-range estimate	4,61	4,61	3,63	4,75
Carbon sequestration (T/ha.year): high-range estimate	3,45	3,45	2,72	3,56
Carbon sequestration (T/year): mid-range estimate	2,65	2,65	2,09	2,73
Carbon sequestration (T/ha.year) : low-range estimate	2,19	2,19	1,72	2,26
FES in % of the total forest area	100,00%	100,00%	15,68%	45,85%

BIODIVERSITE	Deciduous	Coniferous	Mixed
Area total (ha)	*37872,51*	*2709,52*	*2773,84*
mean Carbon stored (T/ha)	102,97	87,38	99,64
Total Carbon stored (T)	3899770,61	236761,03	276385,75
mean Volume (m^3/ha)	417,37	354,18	403,87
Total Volume (m^3)	15806783,56	959653,98	1120263,28
mean Growth (m^3/ha.year): high-range estimate	7,64	3,22	6,19
mean Growth (m^3/ha.year): mid-range estimate	5,87	2,48	4,75
mean Growth (m^3/ha.year): low estimate	4,84	2,05	3,92
Carbon sequestration (T/ha.year): high-range estimate	3,63	1,53	2,94
Carbon sequestration (T/year): mid-range estimate	2,79	1,18	2,26
Carbon sequestration (T/ha.year): low-range estimate	2,30	0,97	1,86
% of forest stands	87,35%	6,25%	6,40%

PRODUCTION	Deciduous	Coniferous	Mixed
Area total (ha)	*37855,16*	*2684,73*	*2766,00*
mean Carbon stored (T/ha)	102,99	87,75	99,63
Total Carbon stored (T)	3898839,64	235585,64	275588,81
mean Volume (m^3/ha)	417,46	355,67	403,84
Total Volume (m^3)	15803010,41	954889,82	1117033,06
mean Growth (m^3/ha.year): high-range estimate	7,64	3,25	6,20
mean Growth (m^3/ha.year): mid-range estimate	5,87	2,50	4,76
mean Growth (m^3/ha.year): low estimate	4,85	2,06	3,94
Carbon sequestration (T/ha.year): high-range estimate	3,63	1,55	2,95
Carbon sequestration (T/year): mid-range estimate	2,79	1,19	2,26
Carbon sequestration (T/ha.year): low-range estimate	2,30	0,98	1,87
% of forest stands	87,41%	6,20%	6,39%

PROTECTIVE	**Deciduous**	**Coniferous**	**Mixed**
Area total (ha)	*5252,27*	*602,07*	*941,79*
mean Carbon (T/ha)	106,78	92,92	102,74
Total Carbon (T)	560855,49	55945,22	96763,08
mean Volume (m^3/ha)	432,82	376,64	416,45
Total Volume (m^3)	2273293,03	226760,53	392205,90
mean Growth (m^3/ha.year): high-range estimate	6,07	3,23	5,52
mean Growth (m^3/ha.year): mid-range estimate	4,66	2,48	4,24
mean Growth (m^3/ha.year): low estimate	3,85	2,05	3,50
Carbon sequestration (T/ha.year): high-range estimate	2,88	1,53	2,62
Carbon sequestration (T/year): mid-range estimate	2,21	1,18	2,01
Carbon sequestration (T/ha.year): low-range estimate	1,83	0,97	1,66
% of forest stands	77,28%	8,86%	13,86%

TOURISM	**Deciduous**	**Coniferous**	**Mixed**
Area total (ha)	*17496,92*	*927,09*	*1456,33*
mean Carbon (T/ha)	103,69	90,80	100,21
Total Carbon (T)	1814228,15	84183,64	145933,76
mean Volume (m^3/ha)	420,28	368,05	406,16
Total Volume (m^3)	7353538,09	341218,15	591507,46
mean Growth (m^3/ha.year): high-range estimate	7,80	3,34	6,27
mean Growth (m^3/ha.year): mid-range estimate	5,99	2,57	4,81
mean Growth (m^3/ha.year): low estimate	4,95	2,12	3,98
Carbon sequestration (T/ha.year): high-range estimate	3,70	1,59	2,98
Carbon sequestration (T/year): mid-range estimate	2,85	1,22	2,29
Carbon sequestration (T/ha.year): low-range estimate	2,35	1,01	1,89
% of forest stands	88,01%	4,66%	7,33%

Total road length within the living lab area (km)	1145,2
Road length protected by protection forests (km)	92
Percentage of roads protected by forest (%)	8,03%

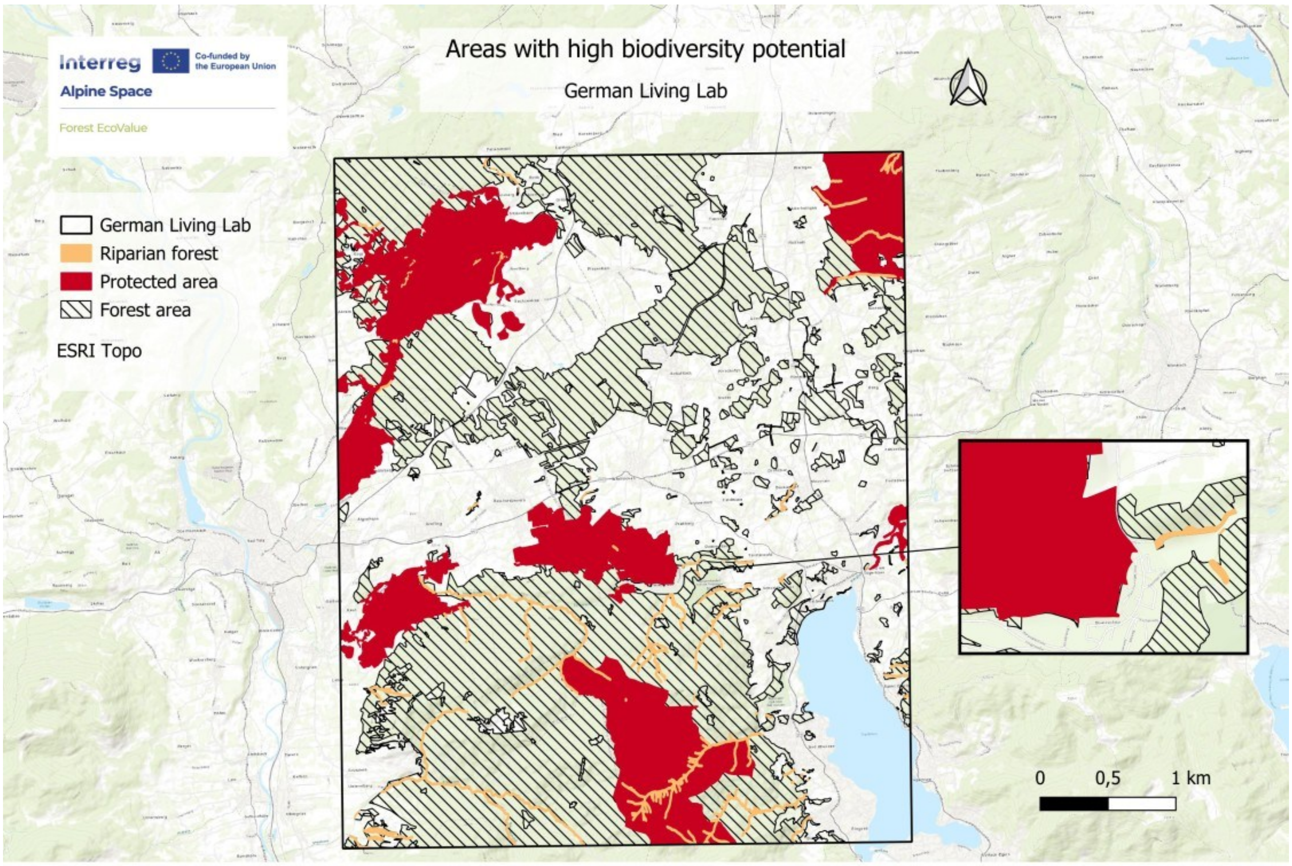
5.4 LL3: Tegernsee Valley, Upper Bavaria

The Tegernsee Valley Living Lab is composed of several forest parcels distributed across four geographical sectors. The map below shows these four sectors.

To carry out the biophysical assessment of ecosystem services (FESs) within this Living Lab, we worked in two stages. The first stage was a testing phase conducted on one of the four geographical sectors, with results presented at the scale of the entire analysis area (a 4 × 5 km rectangle). The second stage consisted of defining an analysis perimeter using a 5 km buffer around the boundaries of the forest parcels. The results of these two stages are presented below.

5.4.1 Results obtained for the test area

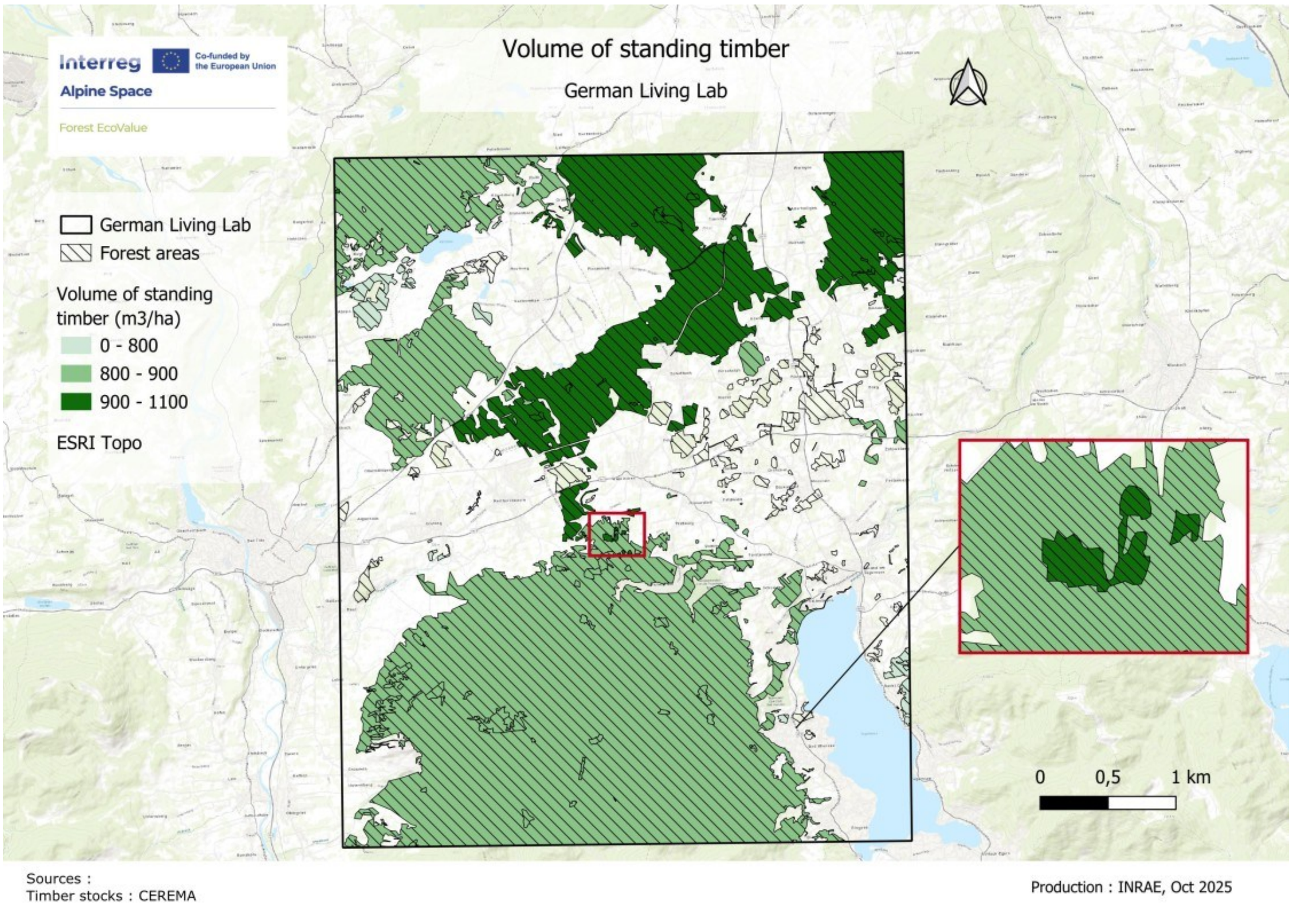
- FES1: map of forest areas with high biodiversity and habitat support potential (support service)



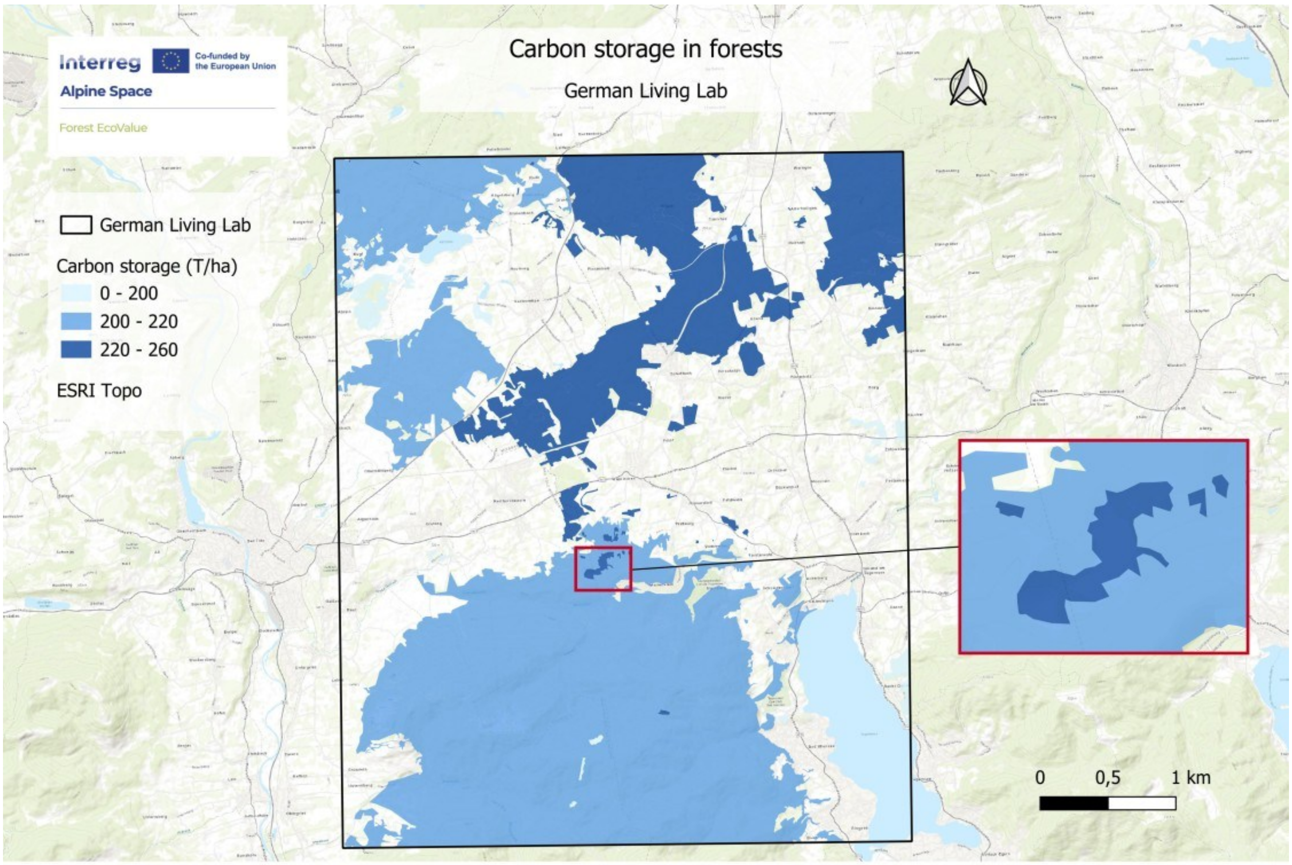
Sources :
Riparian Forest : OpenStreetMap ; Protected areas (Natura 2000) : Europeen Environment Agency ; Forest : OpenStreetMap

Production : INRAE, Oct 2025

- FES 2: map of volume standing timber (timber production service)



- FES3: map of carbon storage in forest areas (regulation service)



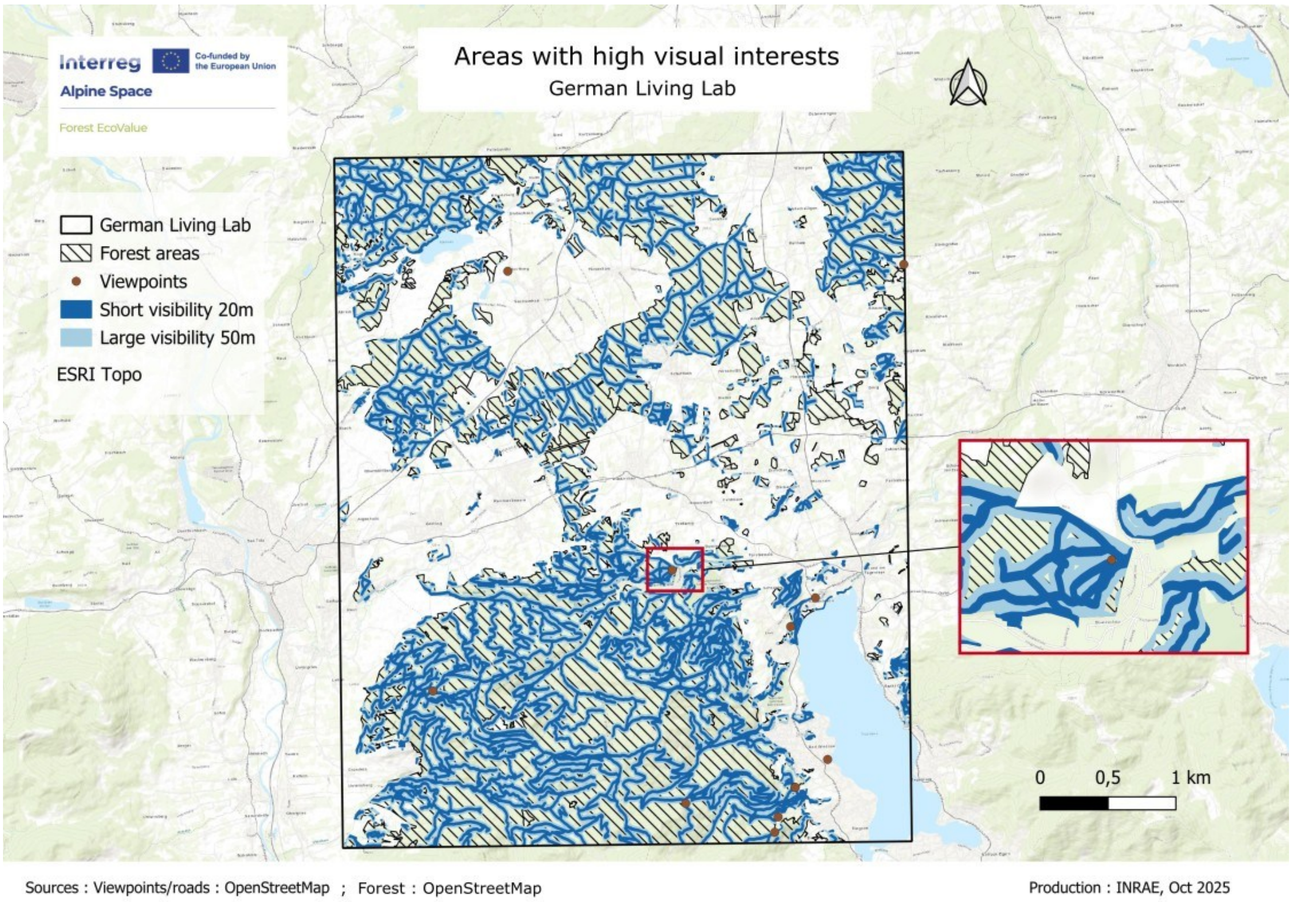
Sources :
Carbon storage : CEREMA

Production : INRAE, Oct 2025

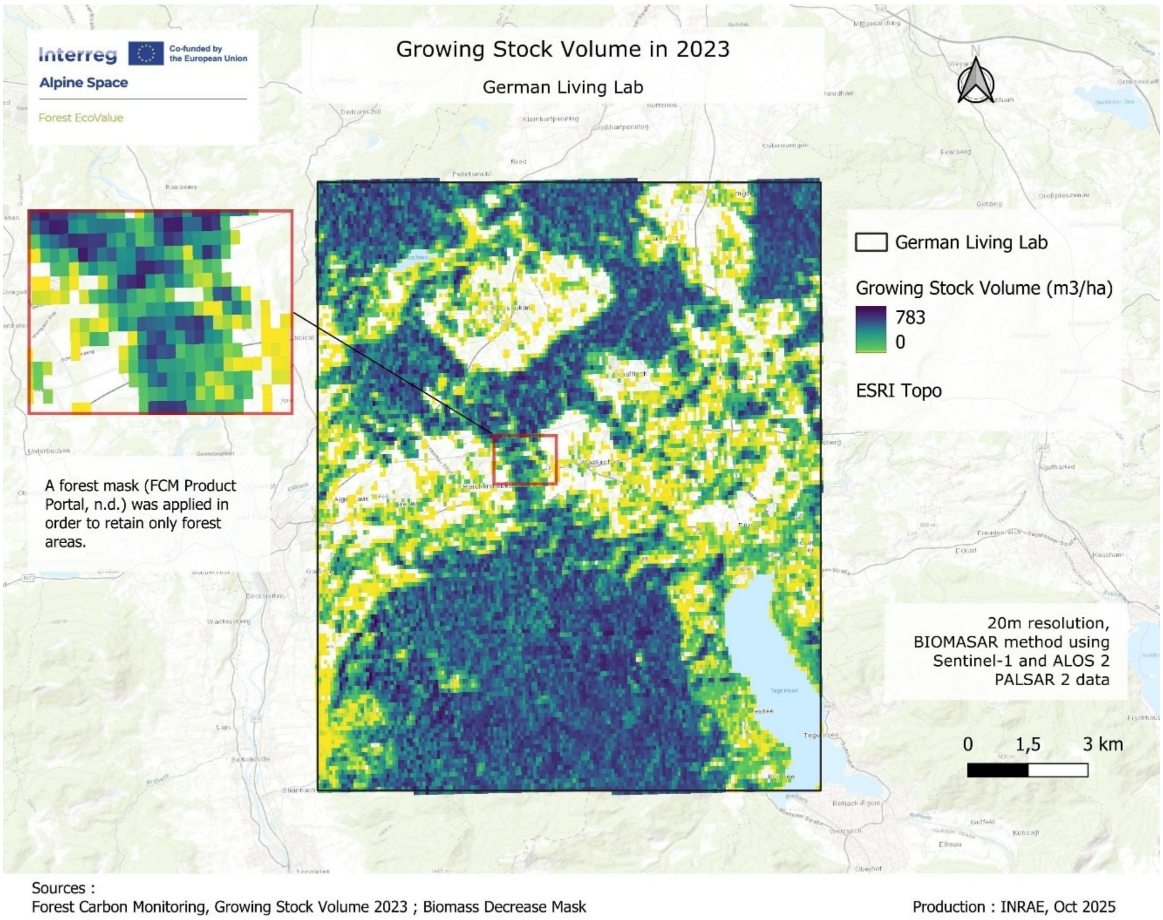
- FES4: map of protective forest against rockfall risks (regulation service)

This living lab is not concerned by this FES.

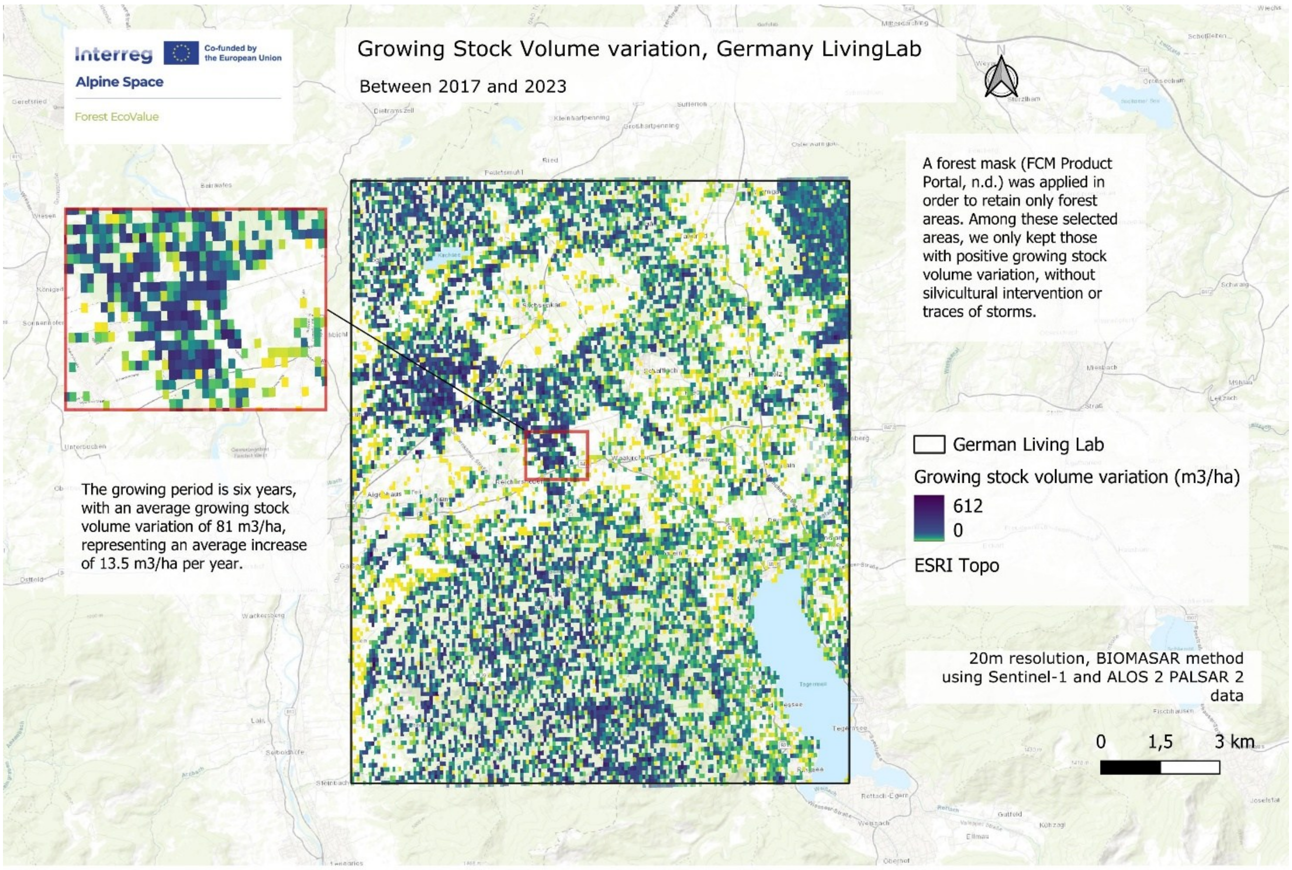
- FES 5: map of high visual interest (cultural service)



- FES 6: map of growing stock volume (regulation and support service)



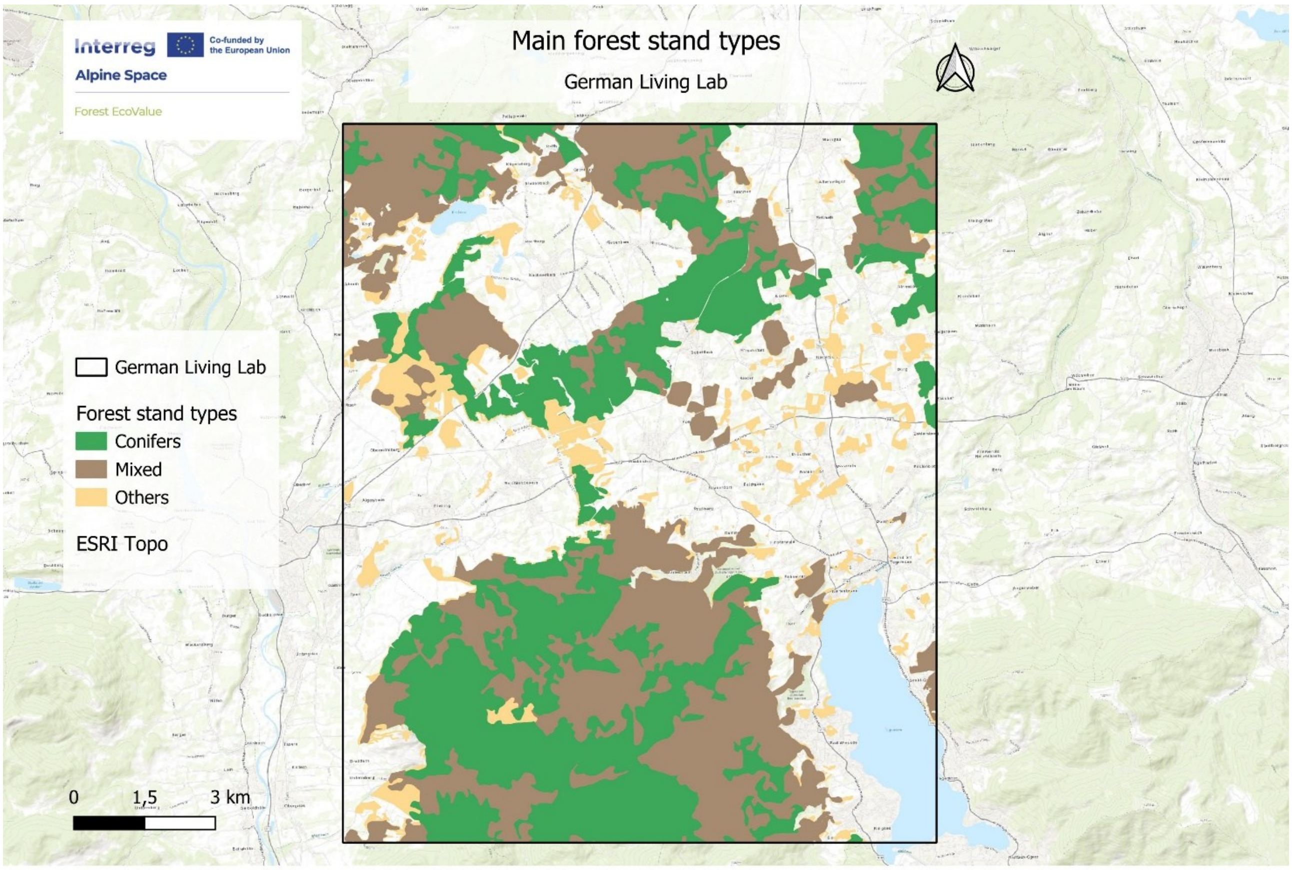
- FES 7: map of growing stock volume increment (regulation and support service)



Sources :
Forest Carbon Monitoring, Growing Stock Volume 2017 and 2023 ; Biomass Decrease Mask

Production : INRAE, Sept 2025

- Map of main forest stand types (supporting all FESs biophysical assessment)



Sources : Copernicus Corine Land Cover (2018)

Production : INRAE, Oct 2025

- *Synthesis table listing each FES with its associated indicator and value*

	Deciduous	Coniferous	Mixed
Area total (ha)	933,91	4364,01	4299,36
mean Carbon stored (T/ha)	210,20	215,53	215,14
Total Carbon stored (T)	196306,67	940586,43	924955,50
mean Volume (m^3/ha)	851,99445	873,6099	872,0106
Total Volume (m^3)	795681,96	3812440,59	3749084,88
mean Growth (m^3/ha.year): high-range estimate	13,07529	16,14553	14,70067
mean Growth (m^3/ha.year): mid-range estimate	10,04	12,40	11,29
mean Growth (m^3/ha.year): low-range estimate	8,29	10,24	9,32
Carbon sequestration (T/year): high estimate	6,21	7,67	6,98
Carbon sequestration (T/year): mid-range estimate	4,77	5,89	5,36
Carbon sequestration (T/year): low-range estimate	3,94	4,86	4,43
% of forest stands	9,73%	45,47%	44,80%

	Biodiversity	Production	Protective	Tourism
Area total (ha)	2996,11	9599,28	55,20	4822,08
mean Carbon stored (T/ha)	135,28	203,16	193,40	204,62
mean Volume (m^3/ha)	548,34	823,47	783,91	829,38
mean Growth (m^3/ha.year): high-range estimate	14,52	16,96	16,93	16,97
mean Growth (m^3/ha.year): mid-range estimate	11,15	13,03	13,00	13,03
mean Growth (m^3/ha.year): low-range estimate	9,21	10,76	10,74	10,76
Carbon sequestration (T/ha.year): high-range estimate	6,90	8,06	8,04	8,06
Carbon sequestration (T/year): mid-range estimate	5,30	6,19	6,18	6,19
Carbon sequestration (T/ha.year) : low-range estimate	4,37	5,11	5,10	5,11
FES in % of the total forest area	31,21%	100,00%	0,58%	50,23%

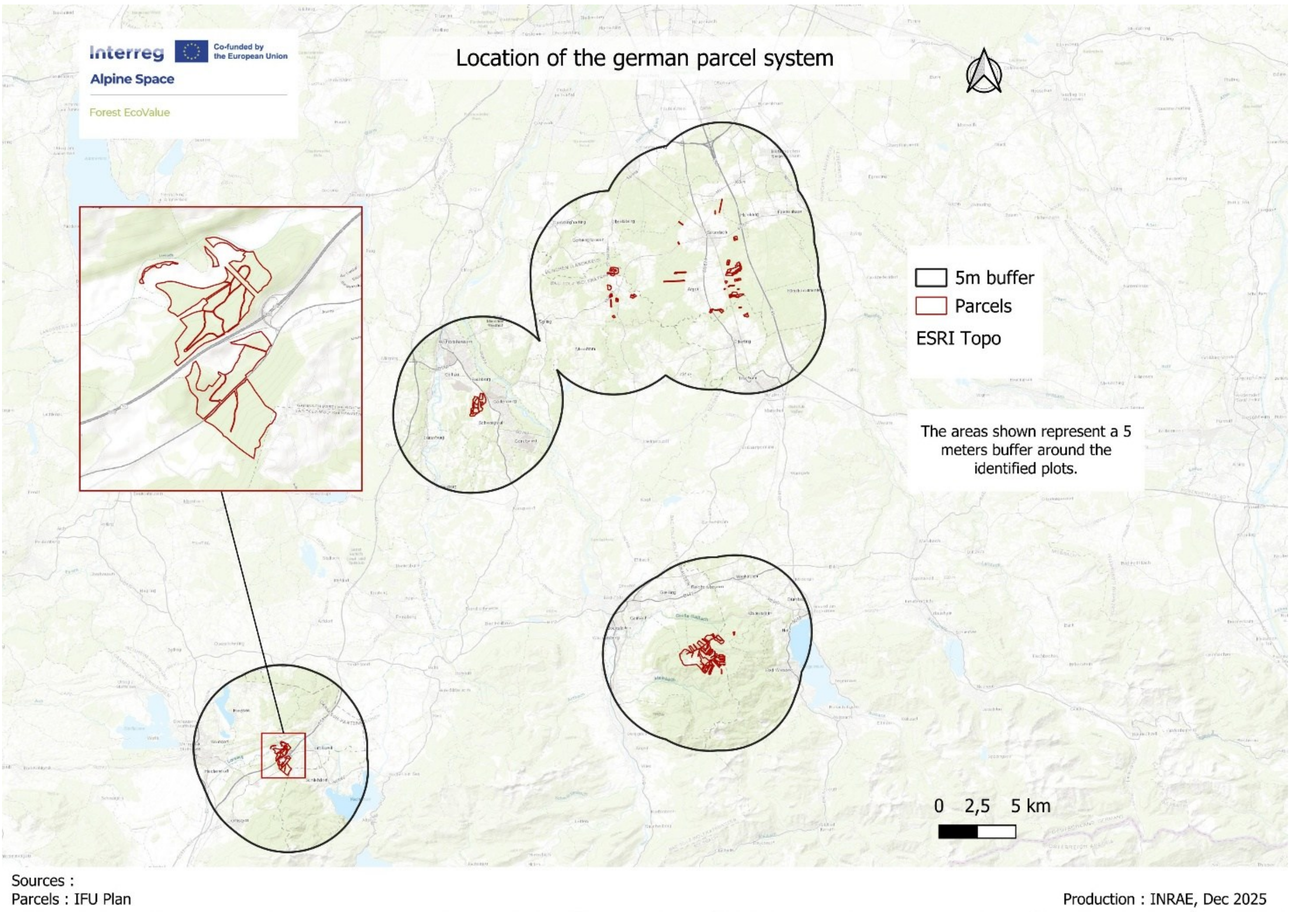
BIODIVERSITE	**Deciduous**	**Coniferous**	**Mixed**
Area total (ha)	*125,97*	*800,72*	*86,35*
mean Carbon stored (T/ha)	26,44	108,85	102,95
Total Carbon stored (T)	3330,14	87158,30	8889,71
mean Volume (m^3/ha)	107,15	441,20	417,28
Total Volume (m^3)	13497,93	353275,23	36032,29
mean Growth (m^3/ha.year): high-range estimate	13,10	18,90	16,01
mean Growth (m^3/ha.year): mid-range estimate	10,06	14,52	12,30
mean Growth (m^3/ha.year): low estimate	8,31	11,99	10,15
Carbon sequestration (T/ha.year): high-range estimate	6,22	8,98	7,60
Carbon sequestration (T/year): mid-range estimate	4,78	6,90	5,84
Carbon sequestration (T/ha.year): low-range estimate	3,95	5,69	4,82
% of forest stands	12,43%	79,04%	8,52%

PRODUCTION	**Deciduous**	**Coniferous**	**Mixed**
Area total (ha)	*931,29*	*4363,59*	*4297,48*
mean Carbon stored (T/ha)	38,48	116,59	108,40
Total Carbon stored (T)	35837,39	508730,42	465865,89
mean Volume (m^3/ha)	155,98	472,55	439,39
Total Volume (m^3)	145258,27	2062016,51	1888275,44
mean Growth (m^3/ha.year): high-range estimate	17,77	17,46	16,26
mean Growth (m^3/ha.year): mid-range estimate	13,65	13,41	12,49
mean Growth (m^3/ha.year): low estimate	11,27	11,07	10,32
Carbon sequestration (T/ha.year): high-range estimate	8,44	8,29	7,73
Carbon sequestration (T/year): mid-range estimate	6,48	6,37	5,93
Carbon sequestration (T/ha.year): low-range estimate	5,35	5,26	4,90
% of forest stands	9,71%	45,49%	44,80%

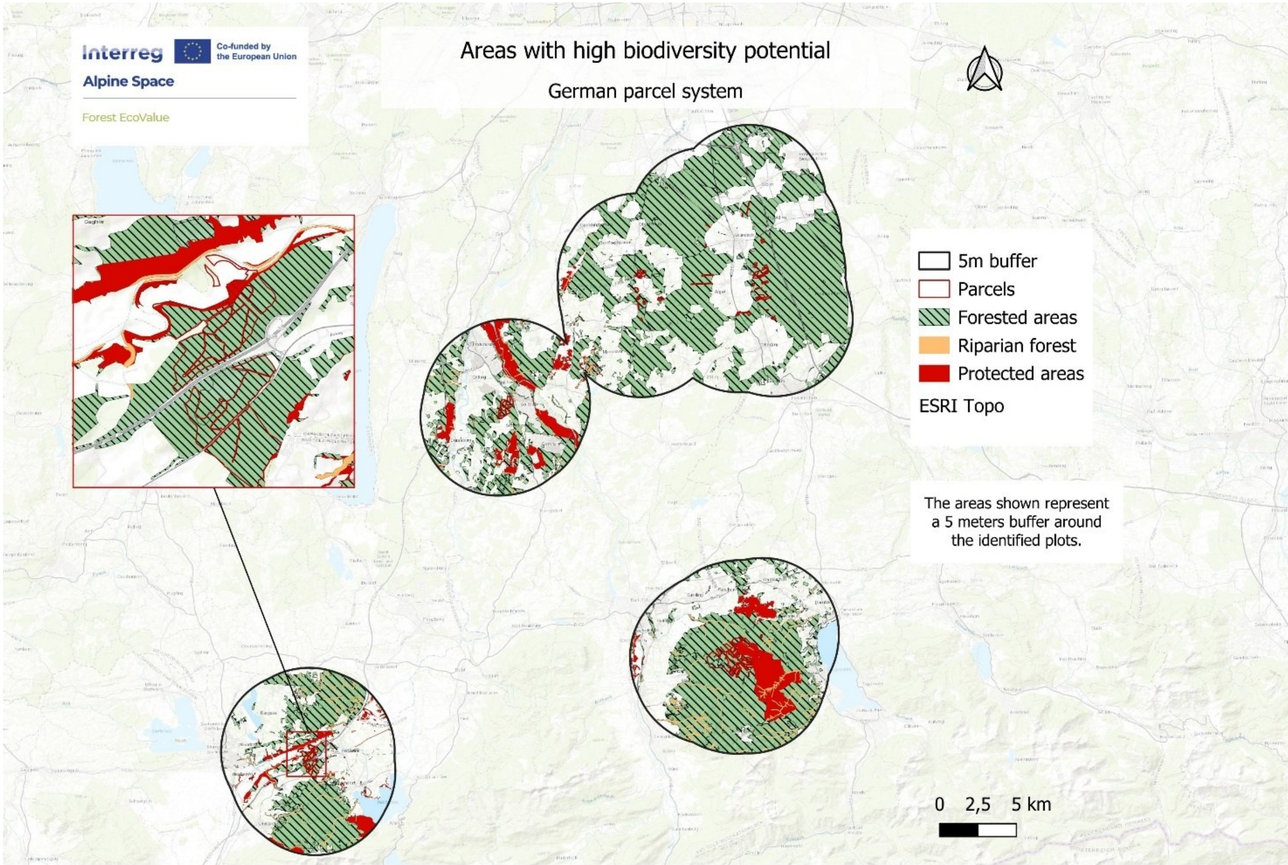
TOURISM	Deciduous	Coniferous	Mixed
Area total (ha)	*760,80*	*3240,80*	*3409,83*
mean Carbon (T/ha)	3,81	109,23	97,75
Total Carbon (T)	2897,45	353988,16	333305,01
mean Volume (m^3/ha)	15,44	442,73	396,20
Total Volume (m^3)	11744,12	1434805,98	1350971,80
mean Growth (m^3/ha.year): high-range estimate	4,02	9,10	7,65
mean Growth (m^3/ha.year): mid-range estimate	3,09	6,99	5,87
mean Growth (m^3/ha.year): low estimate	2,55	5,77	4,85
Carbon sequestration (T/ha.year): high-range estimate	1,91	4,32	3,63
Carbon sequestration (T/year): mid-range estimate	1,47	3,32	2,79
Carbon sequestration (T/ha.year): low-range estimate	1,21	2,74	2,30
% of forest stands	10,27%	43,73%	46,01%

5.4.2 Results obtained for the Living Lab

- Map of the forest parcel location



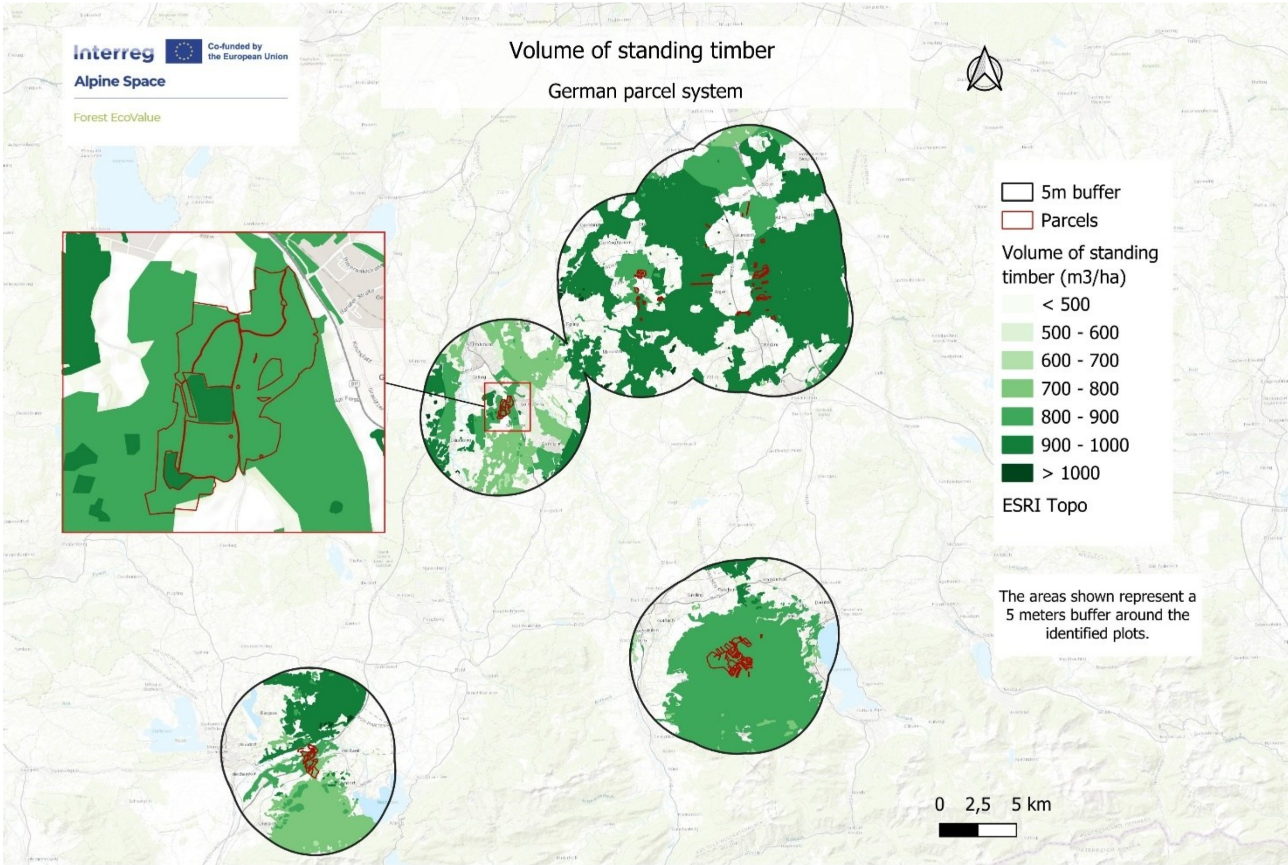
- FES1: map of forest areas with high biodiversity and habitat support potential (support service)



Sources :
Riparian forest : OpenStreetMap ; Protected areas (Natura 2000) : European Environement Agency ; Forest : OpenStreetMap

Production : INRAE, Dec 2025

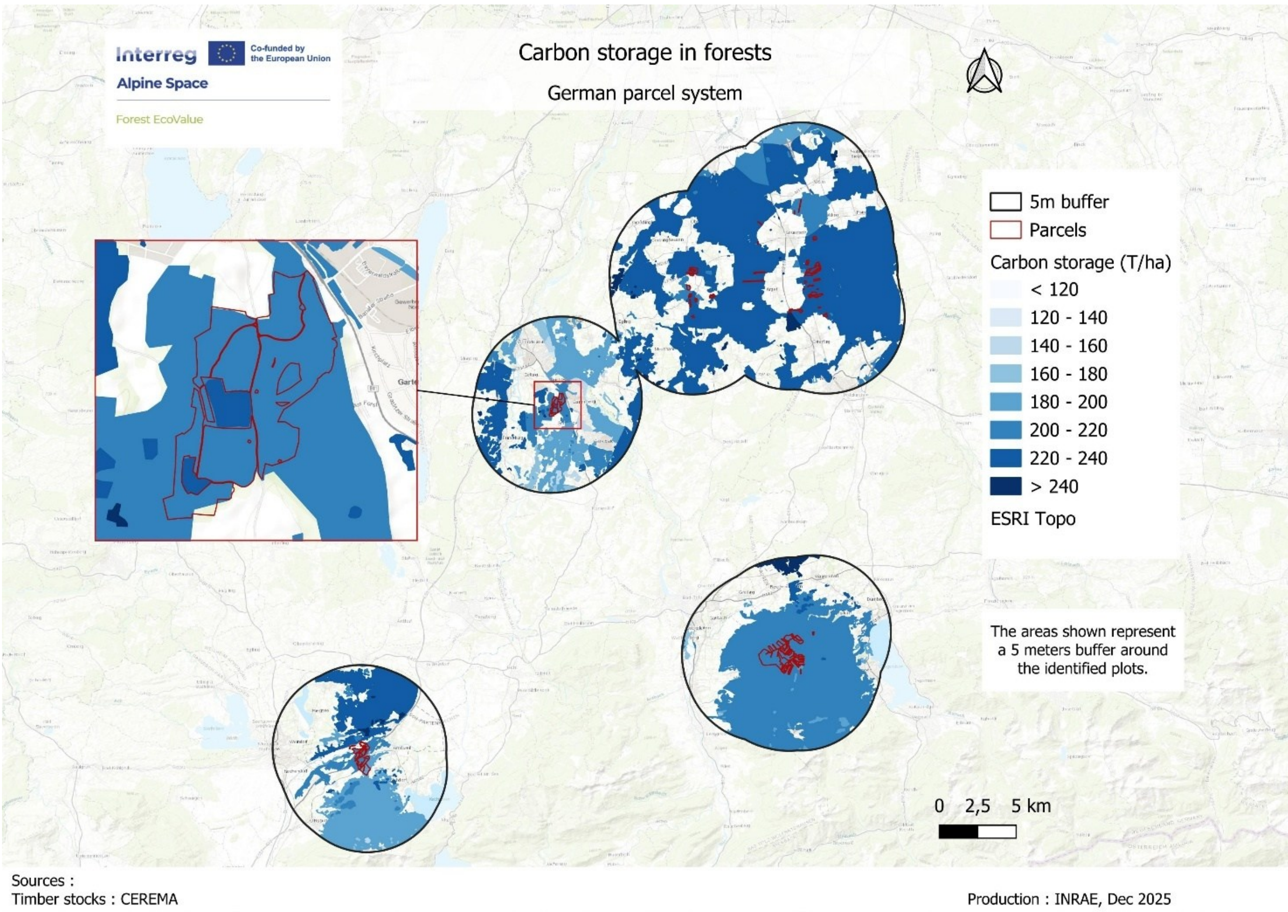
- FES 2: map of volume standing timber (timber production service)



Sources :
Timber stocks : CEREMA

Production : INRAE, Dec 2025

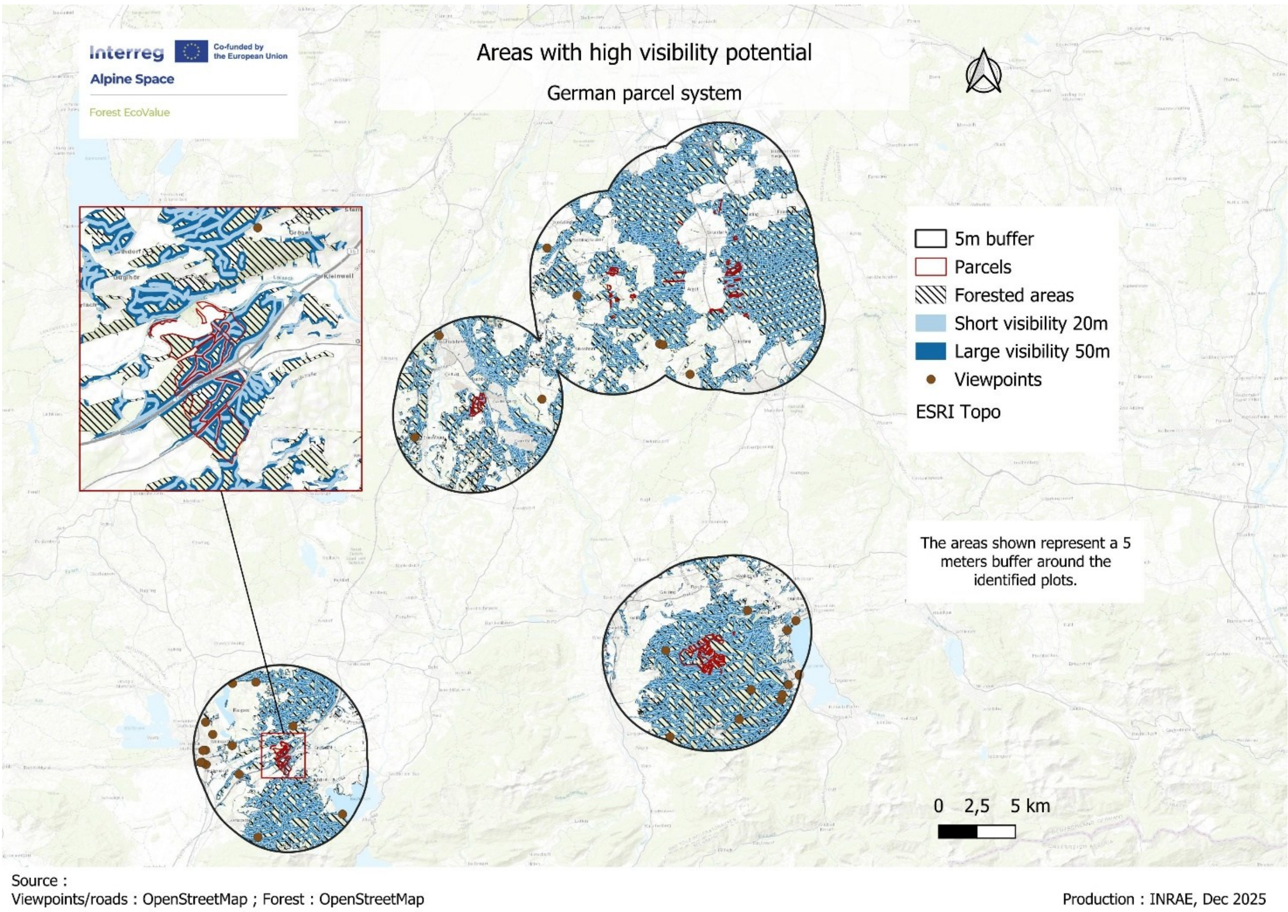
- FES3: map of carbon storage in forest areas (regulation service)



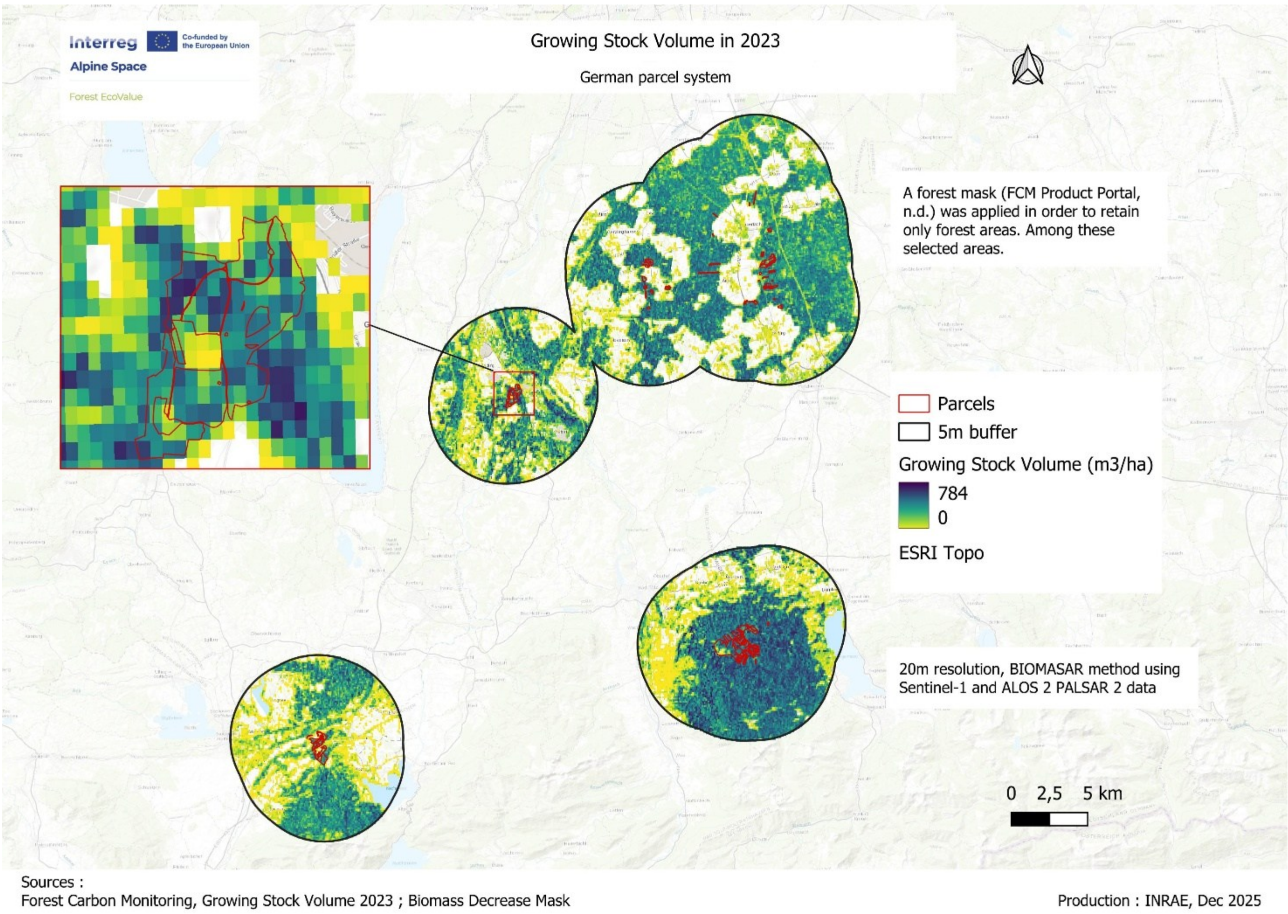
- FES4: map of protective forest against rockfall risks (regulation service)

This living lab is not concerned by this FES.

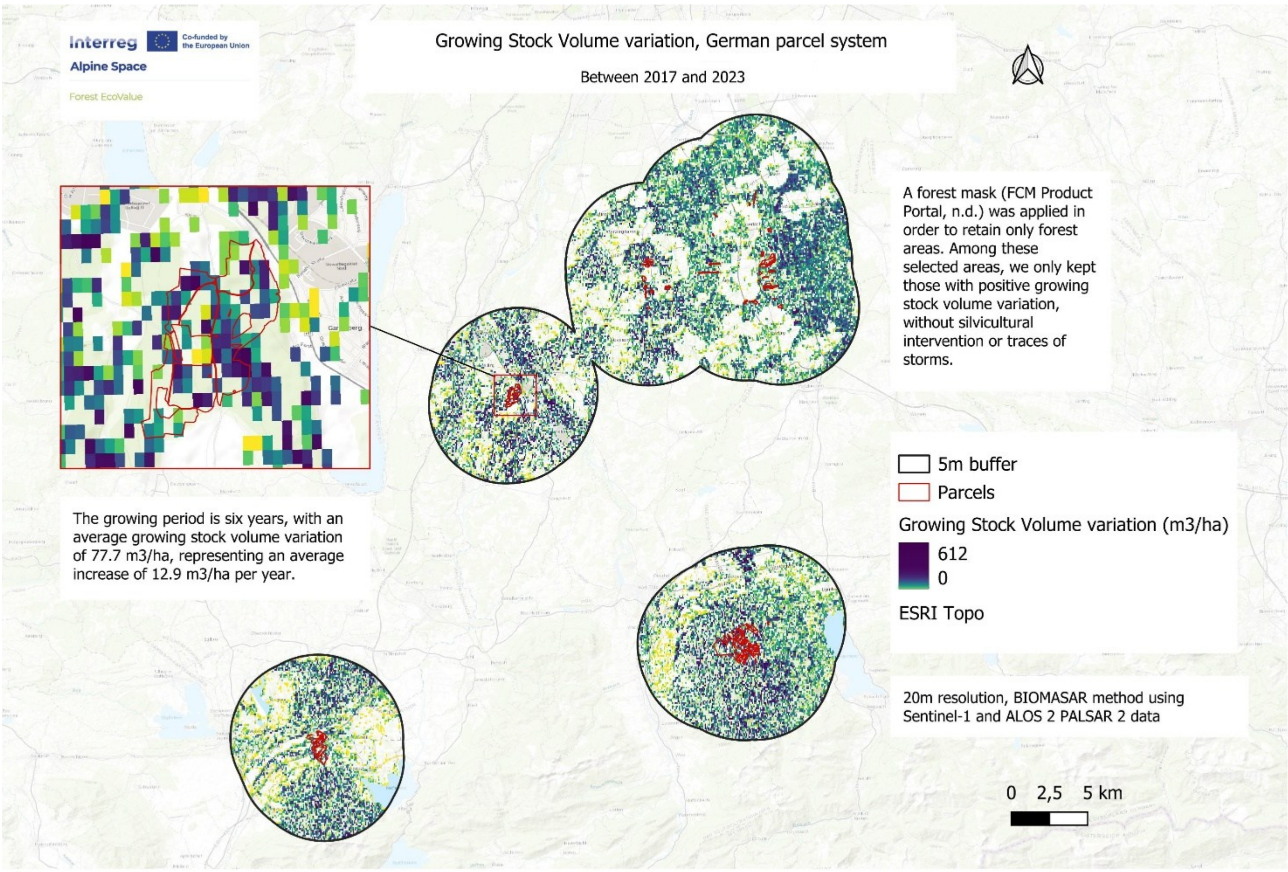
- FES 5: map of high visual interest (cultural service)



- FES 6: map of growing stock volume (regulation and support service)



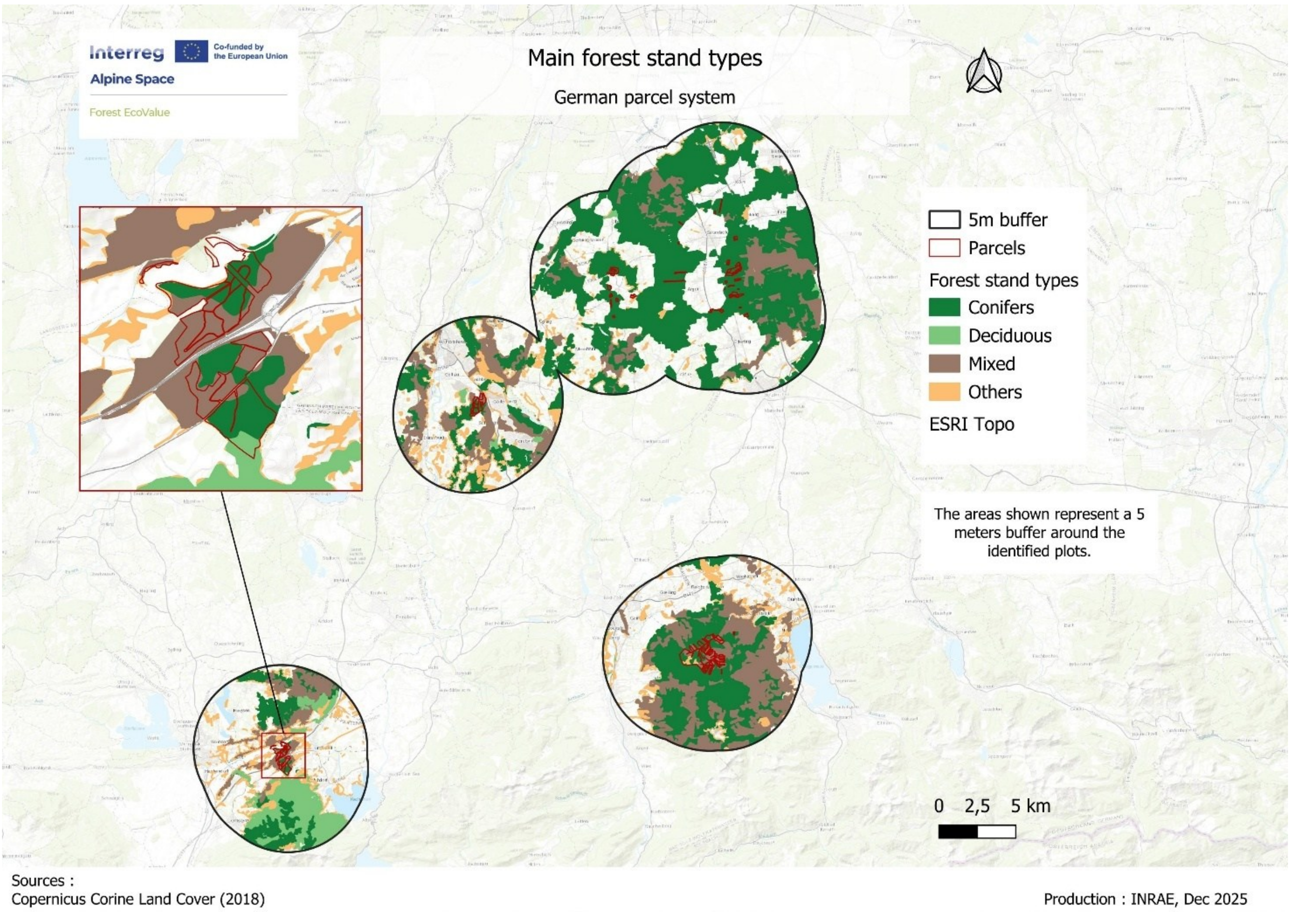
- FES 7: map of growing stock volume increment (regulation and support service)



Sources :
Forest Carbon Monitoring, Growing Stock Volume 2017 and 2023 ; Biomass Decrease Mask

Production : INRAE, Dec 2025

- Map of main forest stand types (supporting all FESs biophysical assessment)



- *Synthesis table listing each FES with its associated indicator and value*

	Deciduous	**Coniferous**	**Mixed**
Area total (ha)	1963,12	18530,83	8867,99
mean Carbon stored (T/ha)	205,35	212,94	209,07
Total Carbon stored (T)	940586,43	196306,67	924955,50
mean Volume (m^3/ha)	832,3532	863,1136	847,4121
Total Volume (m^3)	3812440,59	795681,96	3749084,88
mean Growth (m^3/ha.year): high-range estimate	14,27104	15,60347	15,26148
mean Growth (m^3/ha.year): mid-range estimate	10,96	11,98	11,72
mean Growth (m^3/ha.year): low-range estimate	9,05	9,90	9,68
Total Growth (m^3/year)	28015,71	289145,25	135338,61
Carbon sequestration (T/year): high estimate	6,78	7,41	7,25
Carbon sequestration (T/year): mid-range estimate	5,21	5,69	5,57
Carbon sequestration (T/year): low-range estimate	4,30	4,70	4,60
% of forest stands	6,69%	63,11%	30,20%

	Biodiversity	**Production**	**Protective**	**Tourism**
Area total (ha)	4015,62	31424,97	0,00	19092,04
mean Carbon stored (T/ha)	192,54	210,31	0,00	210,38
mean Volume (m^3/ha)	780,41	852,46	0,00	852,73
mean Growth (m^3/ha.year): high-range estimate	18,00	15,86	0,00	15,45
mean Growth (m^3/ha.year): mid-range estimate	13,82	12,18	0,00	11,87
mean Growth (m^3/ha.year): low-range estimate	11,41	10,06	0,00	9,80
Carbon sequestration (T/ha.year): high-range estimate	8,55	7,53	0,00	7,34
Carbon sequestration (T/year): mid-range estimate	6,56	5,79	0,00	5,64
Carbon sequestration (T/ha.year) : low-range estimate	5,42	4,78	0,00	4,66
FES in % of the total forest area	12,78%	100,00%	0,00%	60,75%

BIODIVERSITE	**Deciduous**	**Coniferous**	**Mixed**
Area total (ha)	*1408,32*	*446,85*	*1601,25*
mean Carbon stored (T/ha)	115,25	109,79	100,30
Total Carbon stored (T)	162314,22	49060,46	160598,76
mean Volume (m^3/ha)	467,15	445,01	406,53
Total Volume (m^3)	657901,42	198854,79	650948,53
mean Growth (m^3/ha.year): high-range estimate	18,38	16,93	16,97
mean Growth (m^3/ha.year): mid-range estimate	14,12	13,01	13,04
mean Growth (m^3/ha.year): low estimate	11,66	10,74	10,77
Total Growth (m^3/year)	25883,98	7567,09	27179,63
Carbon sequestration (T/ha.year): high-range estimate	8,73	8,04	8,06
Carbon sequestration (T/year): mid-range estimate	6,70	6,18	6,19
Carbon sequestration (T/ha.year): low-range estimate	5,54	5,10	5,11
% of forest stands	40,75%	12,93%	46,33%

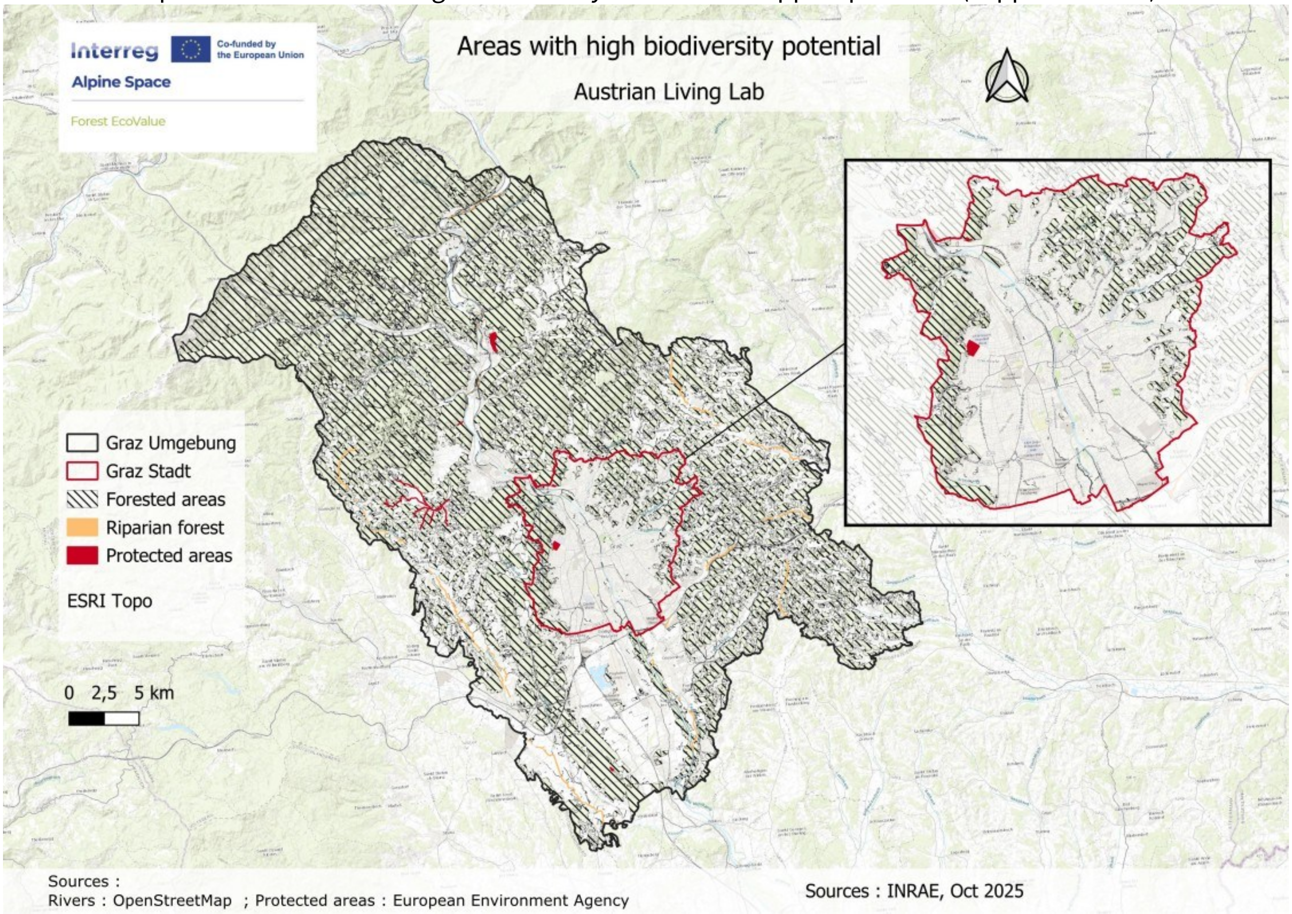
PRODUCTION	**Deciduous**	**Coniferous**	**Mixed**
Area total (ha)	*1961,35*	*18522,51*	*8863,39*
mean Carbon stored (T/ha)	119,60	157,99	94,26
Total Carbon stored (T)	234582,42	35837,39	835463,60
mean Volume (m^3/ha)	484,78	640,36	382,06
Total Volume (m^3)	950823,55	11861140,14	3386350,95
mean Growth (m^3/ha.year): high-range estimate	17,17	15,38	16,88
mean Growth (m^3/ha.year): mid-range estimate	13,18	11,82	12,96
mean Growth (m^3/ha.year): low estimate	10,89	9,76	10,70
Total Growth (m^3/year)	33669,76	284954,48	149582,25
Carbon sequestration (T/ha.year): high-range estimate	8,15	7,31	8,02
Carbon sequestration (T/year): mid-range estimate	6,26	5,61	6,16
Carbon sequestration (T/ha.year): low-range estimate	5,17	4,64	5,08
% of forest stands	6,68%	63,11%	30,20%

TOURISM	Deciduous	Coniferous	Mixed
Area total (ha)	*1224,85*	*11409,69*	*5318,98*
mean Carbon (T/ha)	120,03	158,23	94,57
Total Carbon (T)	147020,80	1805333,92	503034,63
mean Volume (m^3/ha)	486,52	641,34	383,33
Total Volume (m^3)	595913,64	7317486,29	2038929,96
mean Growth (m^3/ha.year): high-range estimate	17,03	14,93	16,42
mean Growth (m^3/ha.year): mid-range estimate	13,08	11,47	12,61
mean Growth (m^3/ha.year): low estimate	10,80	9,47	10,42
Total Growth (m^3/year)	20858,77	170345,56	87342,54
Carbon sequestration (T/ha.year): high-range estimate	4,32	1,91	3,63
Carbon sequestration (T/year): mid-range estimate	6,21	5,45	5,99
Carbon sequestration (T/ha.year): low-range estimate	5,13	4,50	4,95
% of forest stands	6,82%	63,55%	29,63%

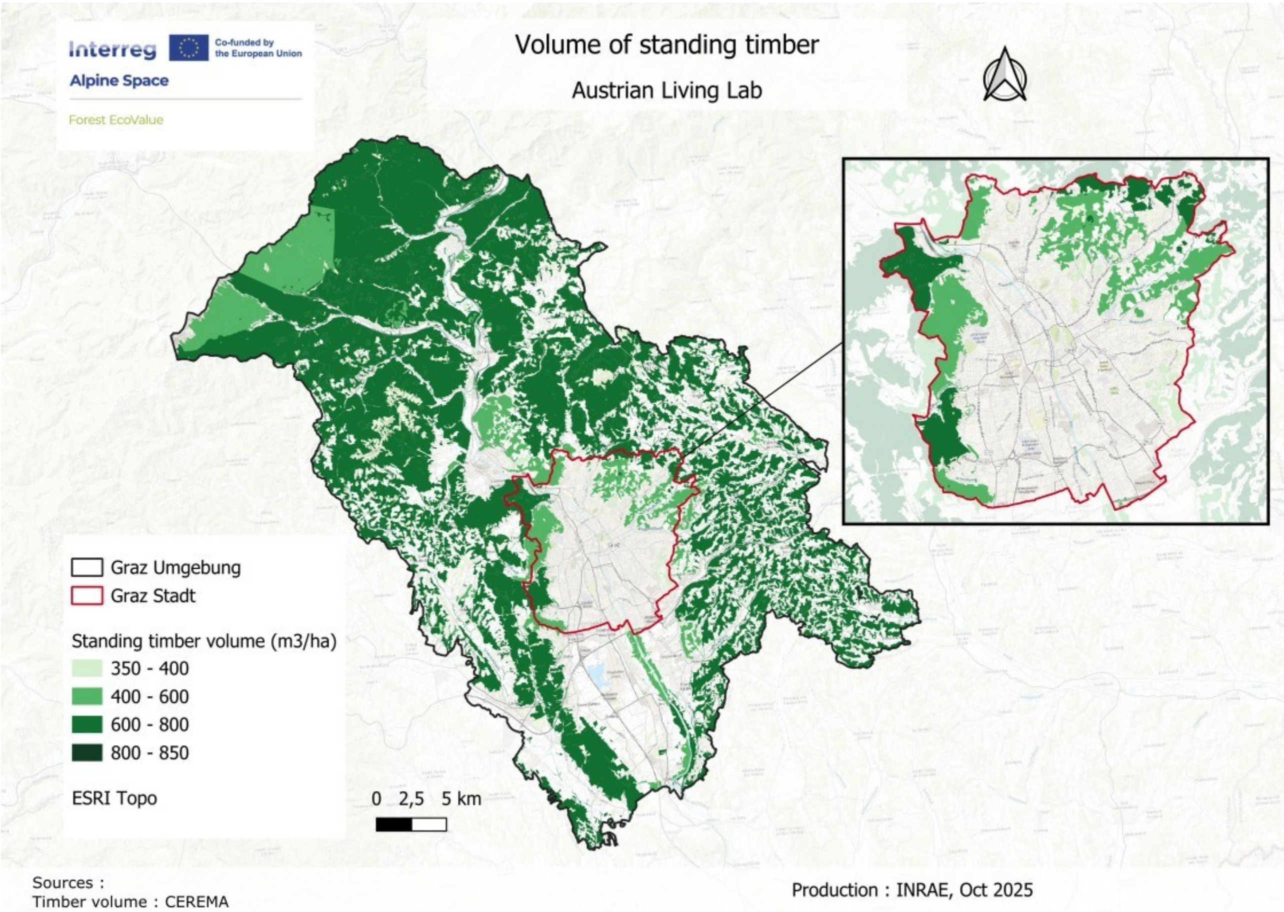
5.5 LL4: Styria

5.5.1 Graz pilot area

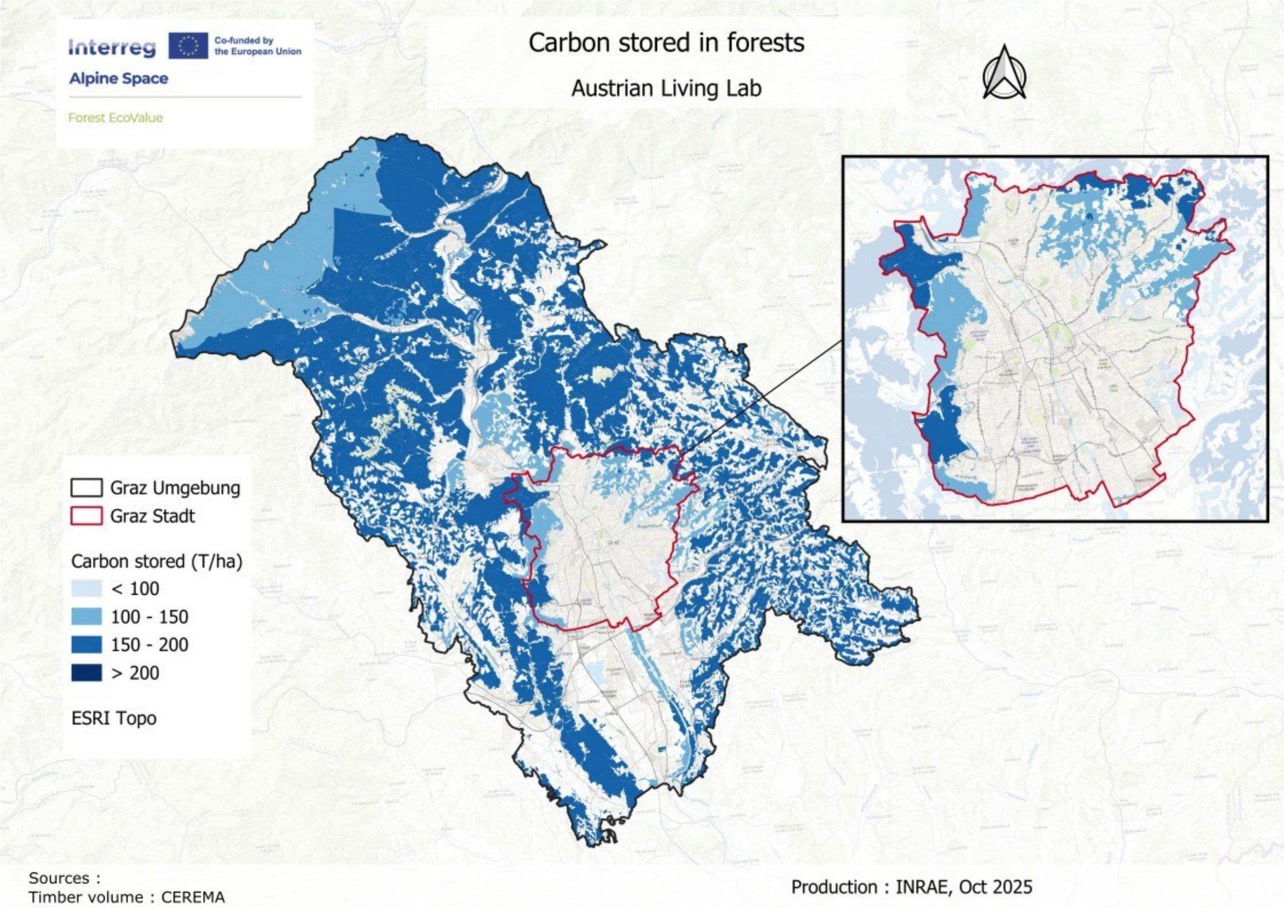
- FES1: map of forest areas with high biodiversity and habitat support potential (support service)



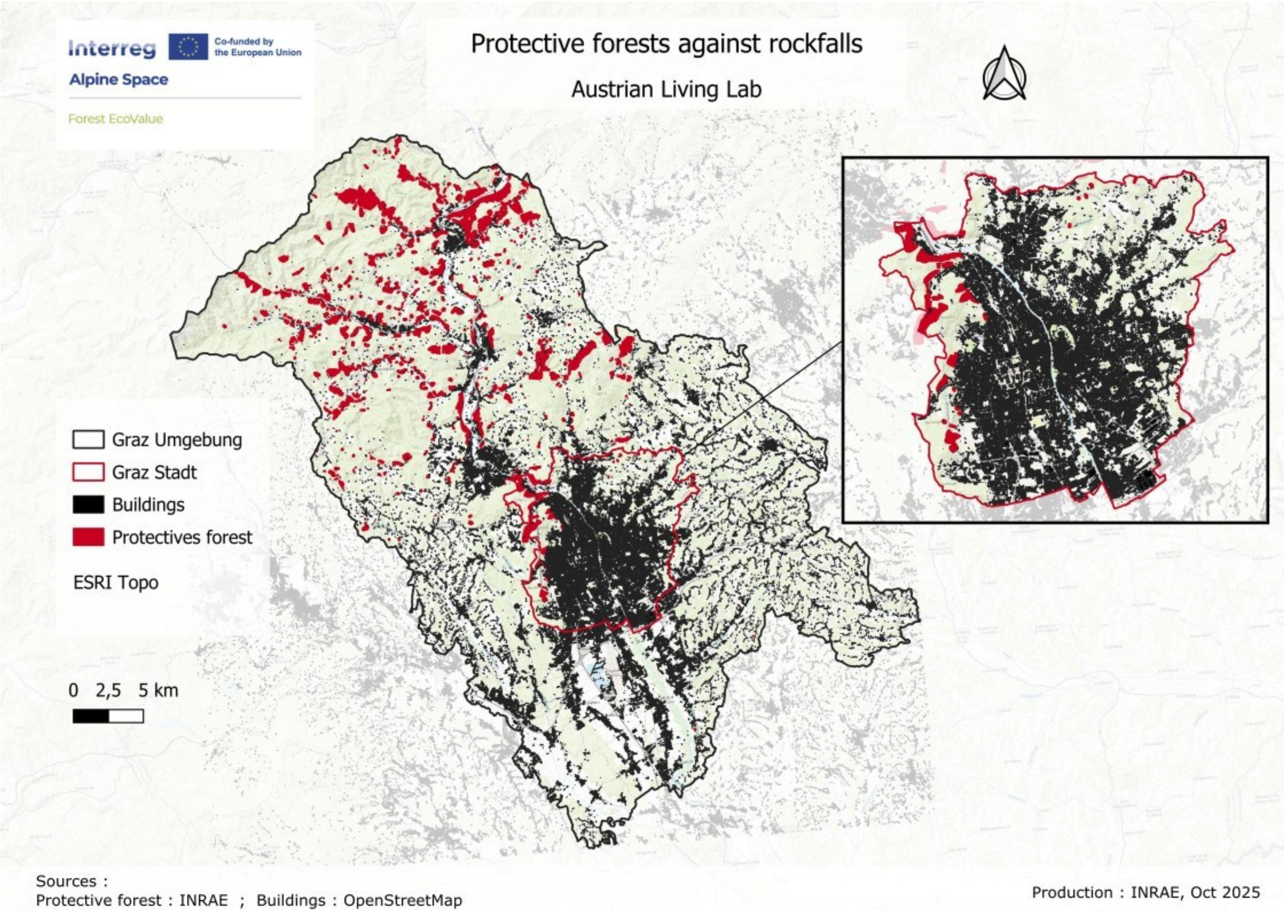
- FES 2: map of volume standing timber (timber production service)



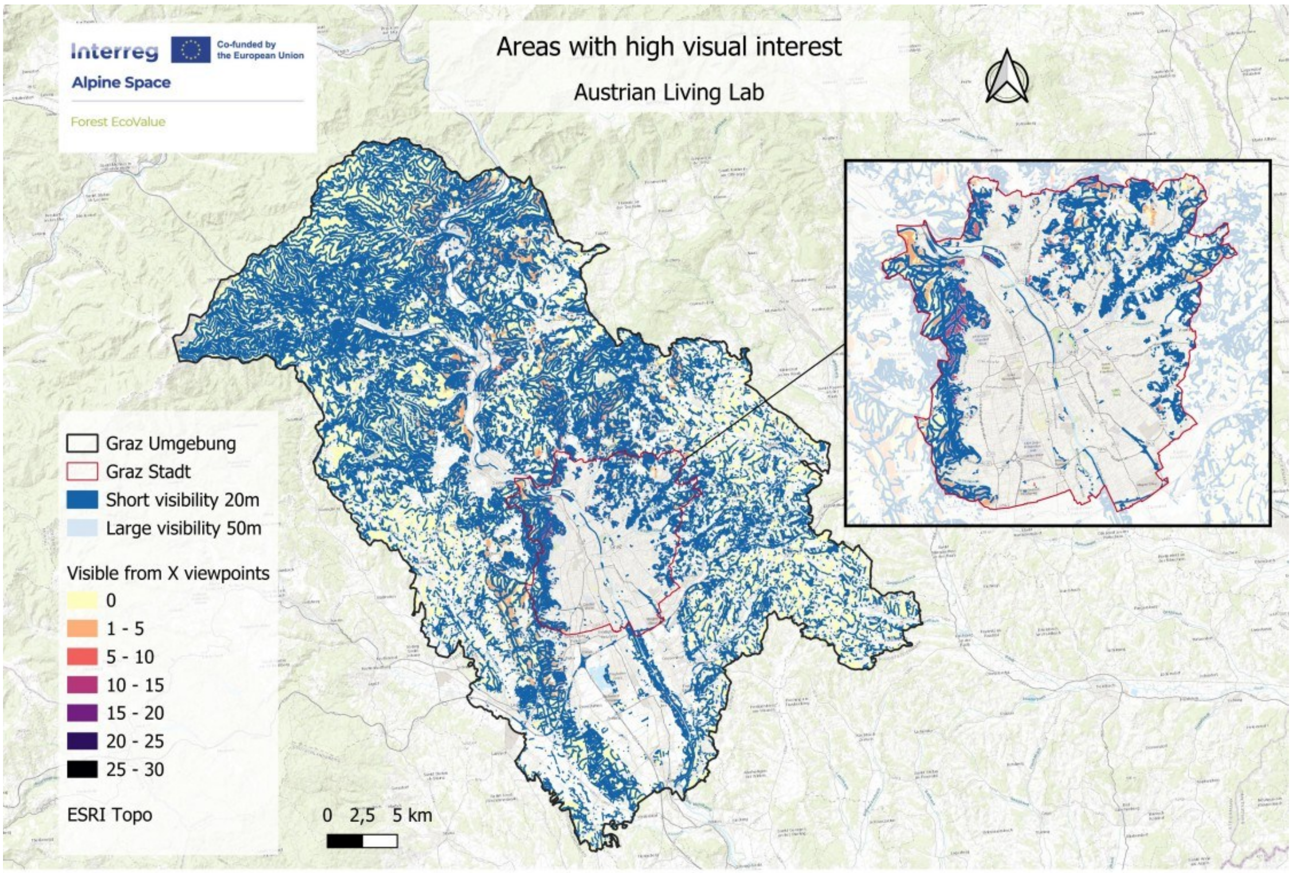
- FES3: map of carbon storage in forest areas (regulation service)



- FES4: map of protective forest against rockfall risks (regulation service)



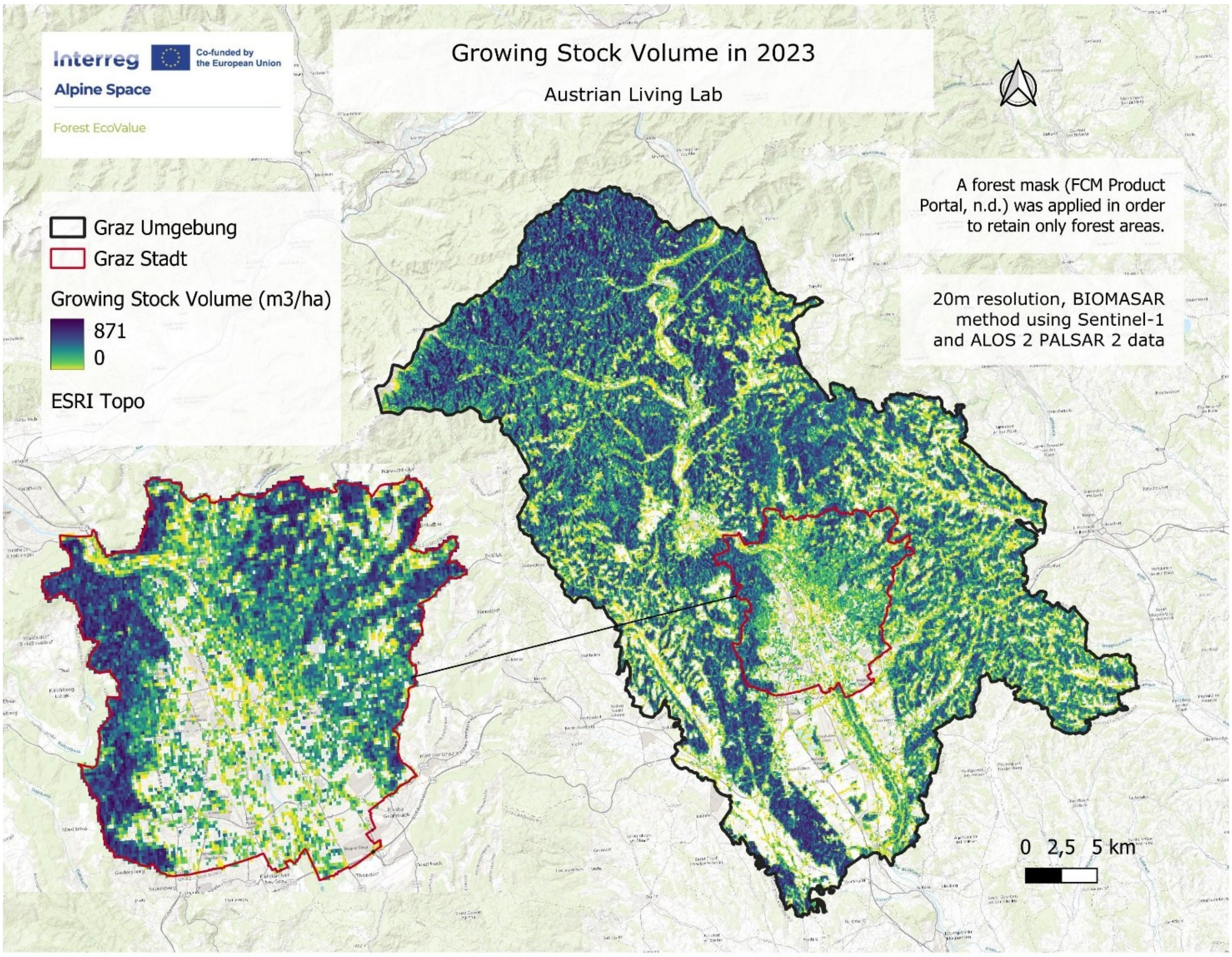
- FES 5: map of high visual interest (cultural service)



Sources :
Roads : OpenStreetMap

Production : INRAE, Oct 2025

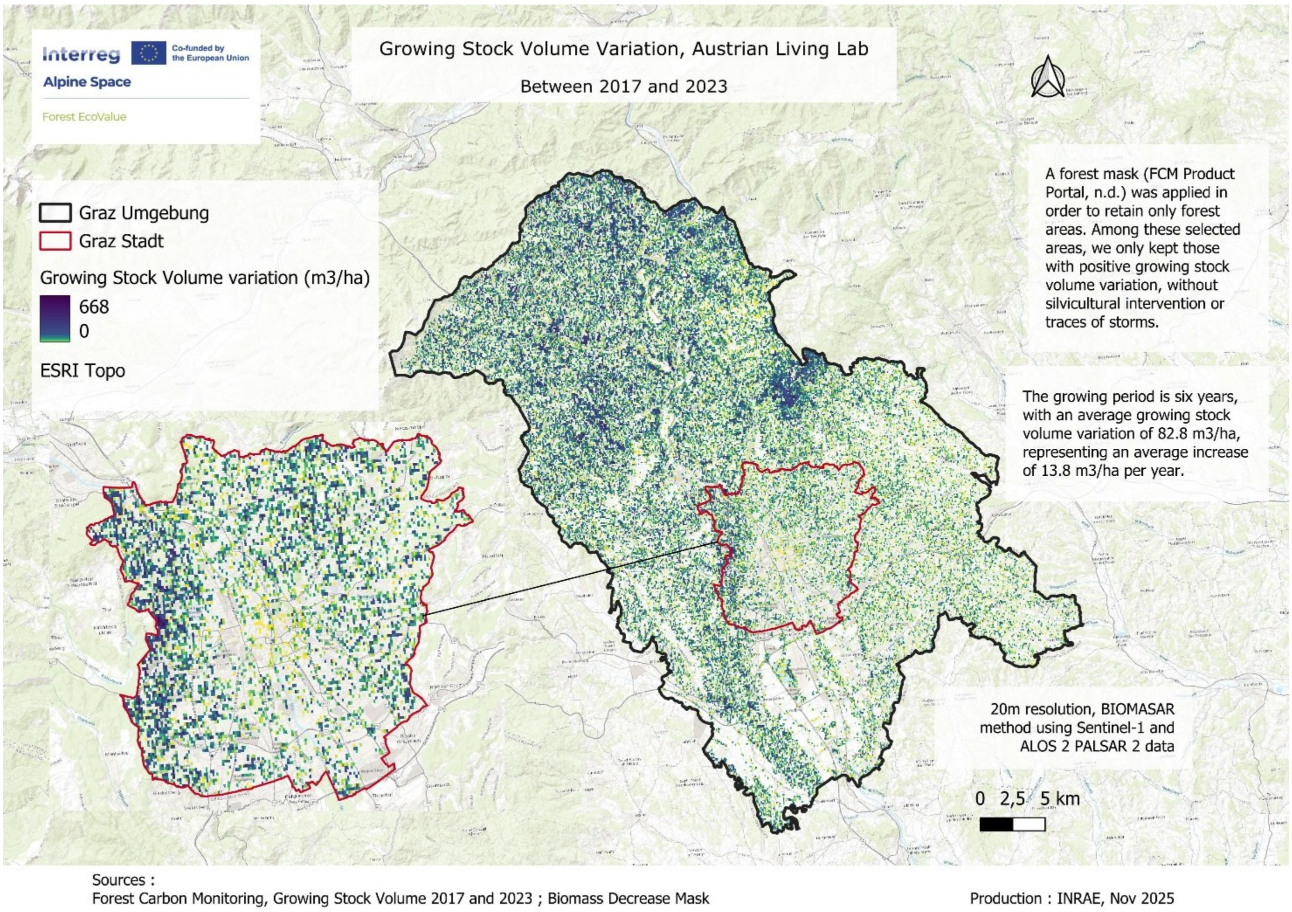
- FES 6: map of growing stock volume (regulation and support service)



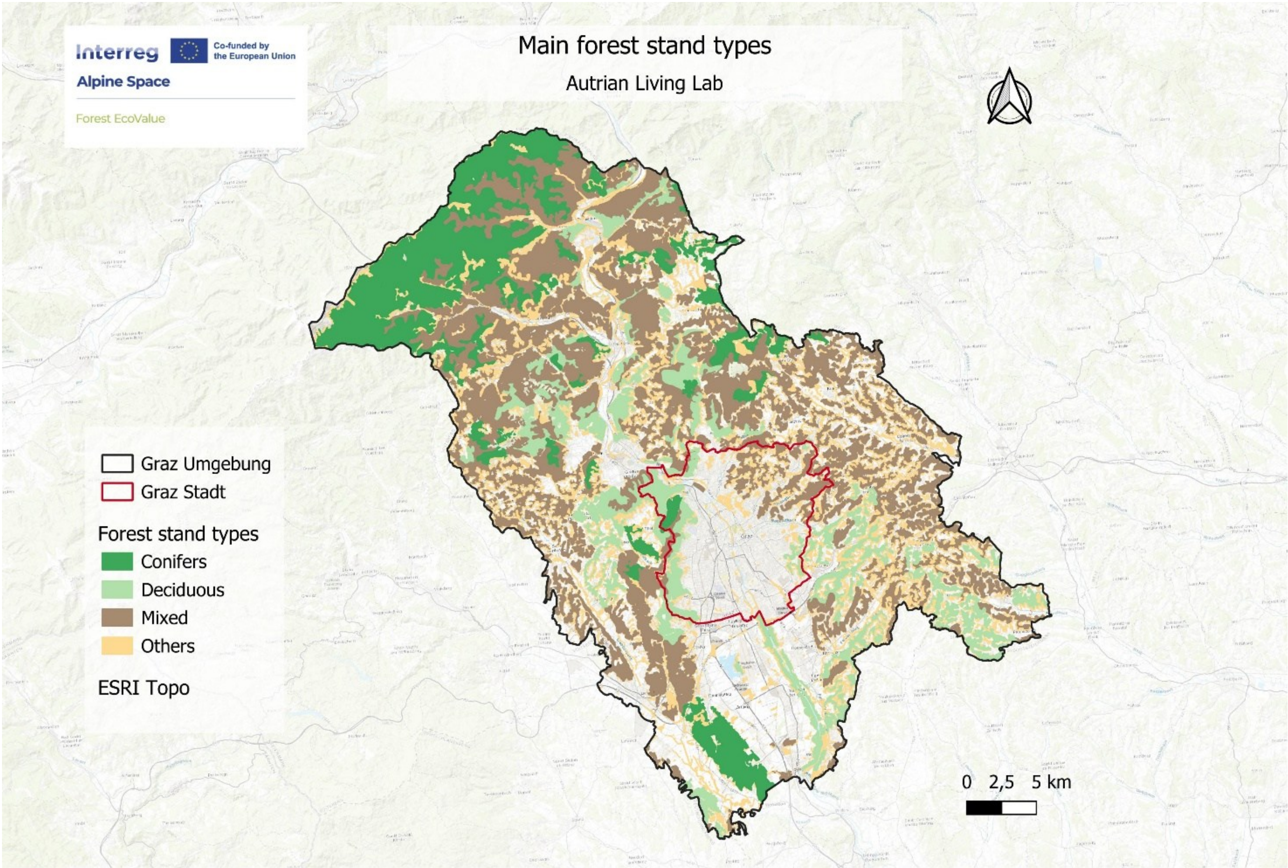
Sources :
Forest Carbon Monitoring, Growing Stock Volume 2023 ; Biomass Decrease Mask

Production : INRAE, Oct 2025

- FES 7: map of growing stock volume increment (regulation and support service)



- Map of main forest stand types (supporting all FESs biophysical assessment)



Sources : Copernicus Corine Land Cover (2018) Production : INRAE, Oct 2025

- *Synthesis table listing each FES with its associated indicator and value*

	Deciduous	Coniferous	Mixed
Area total (ha)	19228,51	16071,08	32067,83
mean Carbon stored (T/ha)	159,39	158,41	166,32
Total Carbon stored (T)	3064860,49	2545869,60	5333608,07
mean Volume (m^3/ha)	646,054996	642,0894	674,1491
Total Volume (m^3)	12422676,89	10319070,11	21618498,73
mean Growth (m^3/ha.year): high-range estimate	11,2084322	15,557	12,96833
mean Growth (m^3/ha.year): mid-range estimate	8,61	11,95	9,96
mean Growth (m^3/ha.year): low-range estimate	7,11	9,87	8,23
Carbon sequestration (T/year): high estimate	5,32	7,39	6,16
Carbon sequestration (T/year): mid-range estimate	4,09	5,68	4,73
Carbon sequestration (T/year): low-range estimate	3,38	4,69	3,91
% of forest stands	28,54%	23,86%	47,60%

	Biodiversity	Production	Protective	Tourism
Area total (ha)	221,77	67367,42	4935,44	48167,90
mean Carbon stored (T/ha)	148,25	159,16	151,84	158,33
mean Volume (m^3/ha)	600,88	645,13	615,44	641,77
mean Growth (m^3/ha.year): high-range estimate	13,36	14,94	19,01	15,96
mean Growth (m^3/ha.year): mid-range estimate	10,26	11,47	14,60	12,26
mean Growth (m^3/ha.year): low-range estimate	8,47	9,47	12,06	10,12
Carbon sequestration (T/ha.year): high-range estimate	6,34	7,09	9,03	7,58
Carbon sequestration (T/year): mid-range estimate	4,87	5,45	6,94	5,82
Carbon sequestration (T/ha.year) : low-range estimate	4,02	4,50	5,73	4,81
FES in % of the total forest area	0,33%	100,00%	7,33%	71,50%

BIODIVERSITE	Deciduous	Coniferous	Mixed
Area total (ha)	*159,55*	*4,37*	*51,96*
mean Carbon stored (T/ha)	97,56	150,51	137,92
Total Carbon stored (T)	15564,97	658,31	7166,84
mean Volume (m^3/ha)	395,42	610,04	559,04
Total Volume (m^3)	63088,87	2668,32	29049,07
mean Growth (m^3/ha.year): high-range estimate	8,25	13,05	12,06
mean Growth (m^3/ha.year): mid-range estimate	6,34	10,02	9,26
mean Growth (m^3/ha.year): low estimate	5,23	8,28	7,65
Carbon sequestration (T/ha.year): high-range estimate	3,92	6,20	5,73
Carbon sequestration (T/year): mid-range estimate	3,01	4,76	4,40
Carbon sequestration (T/ha.year): low-range estimate	2,49	3,93	3,63
% of forest stands	73,90%	2,03%	24,07%

PRODUCTION	Deciduous	Coniferous	Mixed
Area total (ha)	*19067,97*	*16056,20*	*32009,59*
mean Carbon stored (T/ha)	79,27	100,96	112,69
Total Carbon stored (T)	1511574,18	1620999,85	3607288,91
mean Volume (m^3/ha)	321,31	409,21	456,78
Total Volume (m^3)	6126802,86	6570333,46	14621278,83
mean Growth (m^3/ha.year): high-range estimate	12,93	17,36	14,92
mean Growth (m^3/ha.year): mid-range estimate	9,93	13,34	11,46
mean Growth (m^3/ha.year): low estimate	8,20	11,01	9,46
Carbon sequestration (T/ha.year): high-range estimate	6,14	8,25	7,09
Carbon sequestration (T/year): mid-range estimate	4,72	6,33	5,44
Carbon sequestration (T/ha.year): low-range estimate	3,89	5,23	4,50
% of forest stands	28,40%	23,92%	47,68%

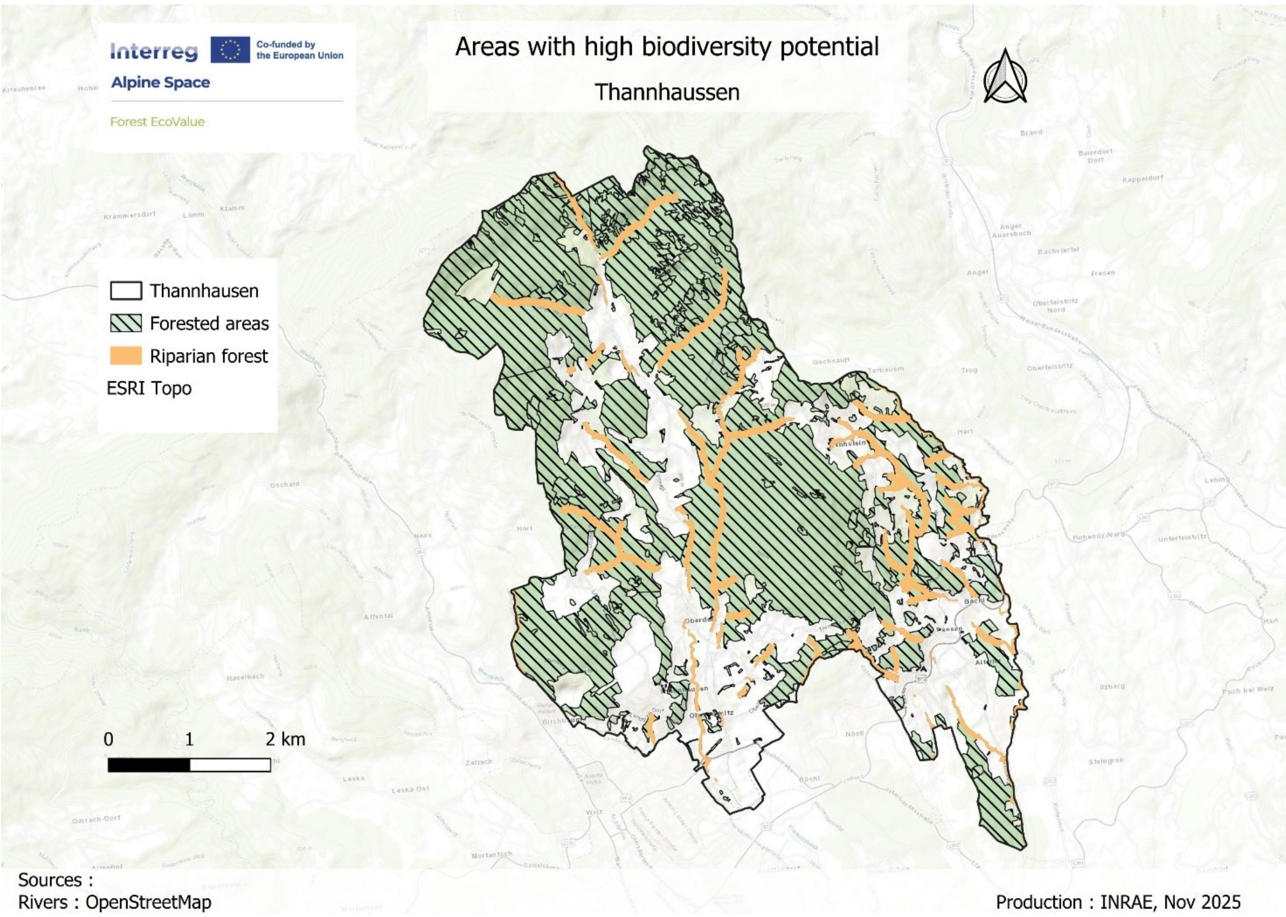
PROTECTIVE	Deciduous	Coniferous	Mixed
Area total (ha)	*1119,12*	*1042,44*	*2529,69*
mean Carbon (T/ha)	90,49	91,72	138,09
Total Carbon (T)	101270,23	95613,49	349313,51
mean Volume (m^3/ha)	366,78	371,77	559,70
Total Volume (m^3)	410474,54	387546,35	1415858,40
mean Growth (m^3/ha.year): high-range estimate	17,16	17,43	12,55
mean Growth (m^3/ha.year): mid-range estimate	13,18	13,39	9,64
mean Growth (m^3/ha.year): low estimate	10,88	11,06	7,96
Carbon sequestration (T/ha.year): high-range estimate	8,15	8,28	5,96
Carbon sequestration (T/year): mid-range estimate	6,26	6,36	4,58
Carbon sequestration (T/ha.year): low-range estimate	5,17	5,25	3,78
% of forest stands	23,86%	22,22%	53,92%

TOURISM	Deciduous	Coniferous	Mixed
Area total (ha)	*13822,77*	*11564,51*	*22755,44*
mean Carbon (T/ha)	76,07	99,48	109,84
Total Carbon (T)	1051498,64	1150380,07	2499530,26
mean Volume (m^3/ha)	308,33	403,20	445,22
Total Volume (m^3)	4261997,23	4662789,49	10131245,38
mean Growth (m^3/ha.year): high-range estimate	14,38	17,45	16,51
mean Growth (m^3/ha.year): mid-range estimate	11,05	13,40	12,68
mean Growth (m^3/ha.year): low estimate	9,12	11,07	10,47
Carbon sequestration (T/ha.year): high-range estimate	6,83	8,29	7,84
Carbon sequestration (T/year): mid-range estimate	5,25	6,37	6,02
Carbon sequestration (T/ha.year): low-range estimate	4,33	5,26	4,97
% of forest stands	28,71%	24,02%	47,27%

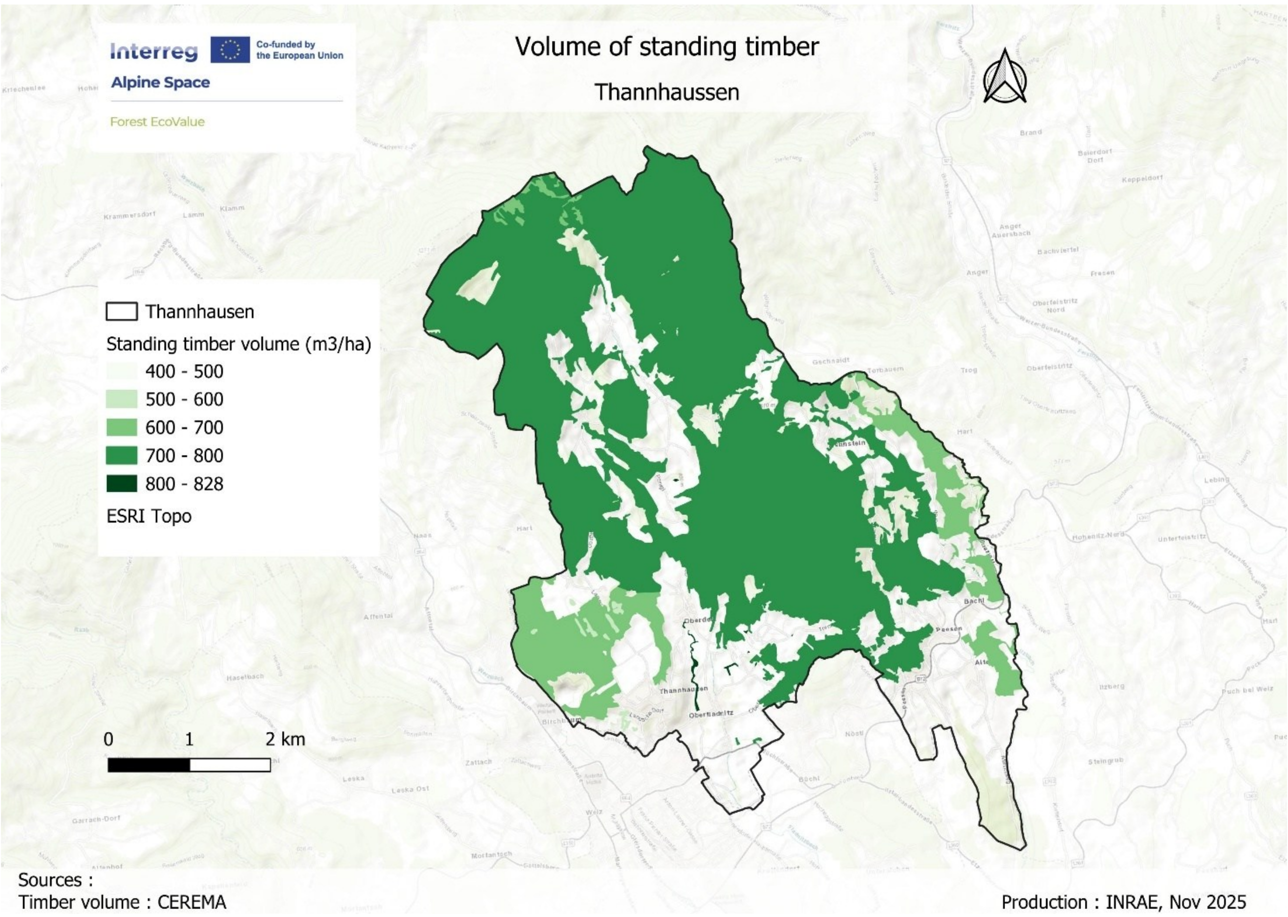
Total road length within the living lab area (km)	6142,7
Road length protected by protection forests (km)	111,1
Percentage of roads protected by forest (%)	1,81%

5.5.2 Thannhausen pilot area

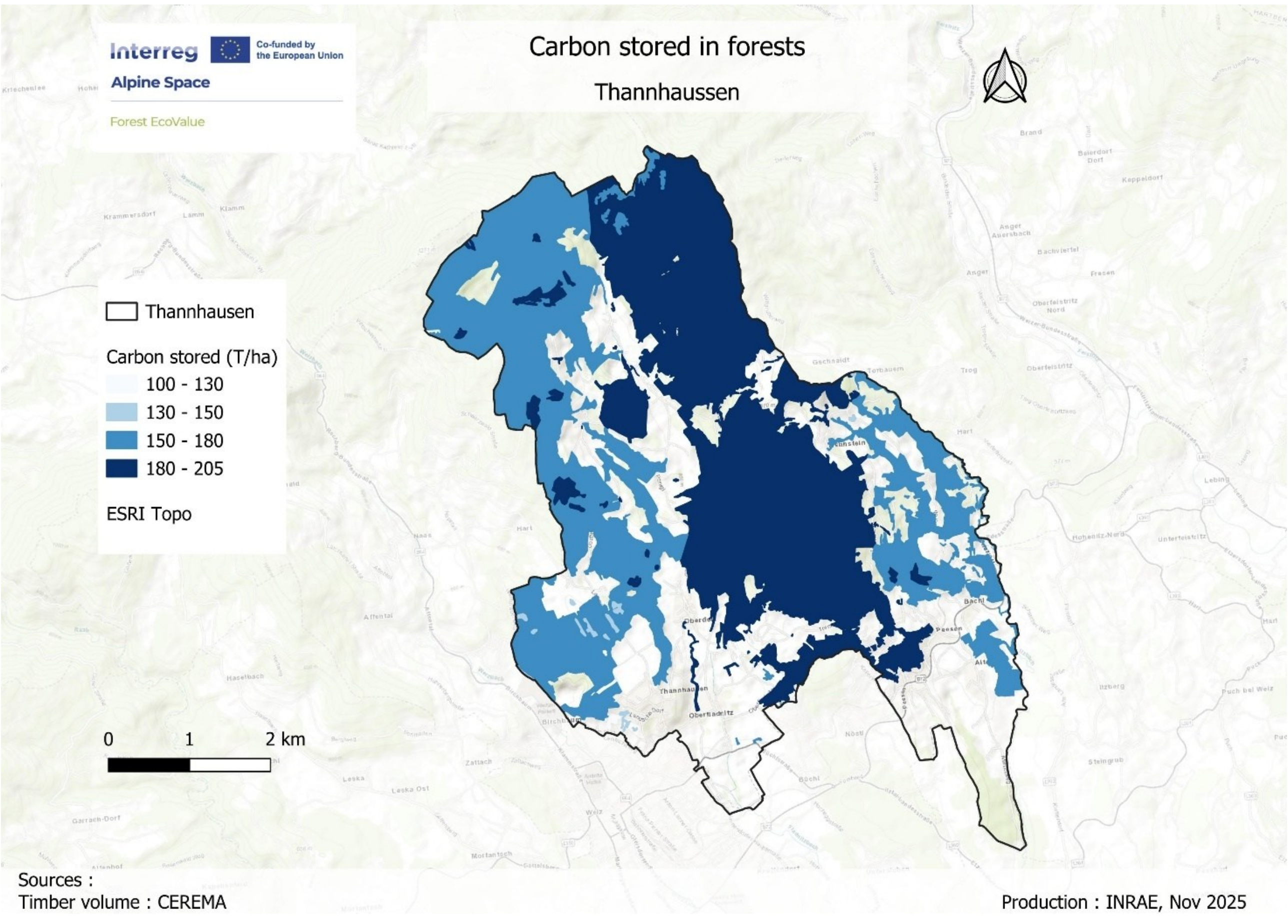
- FES1: map of forest areas with high biodiversity and habitat support potential (support service)



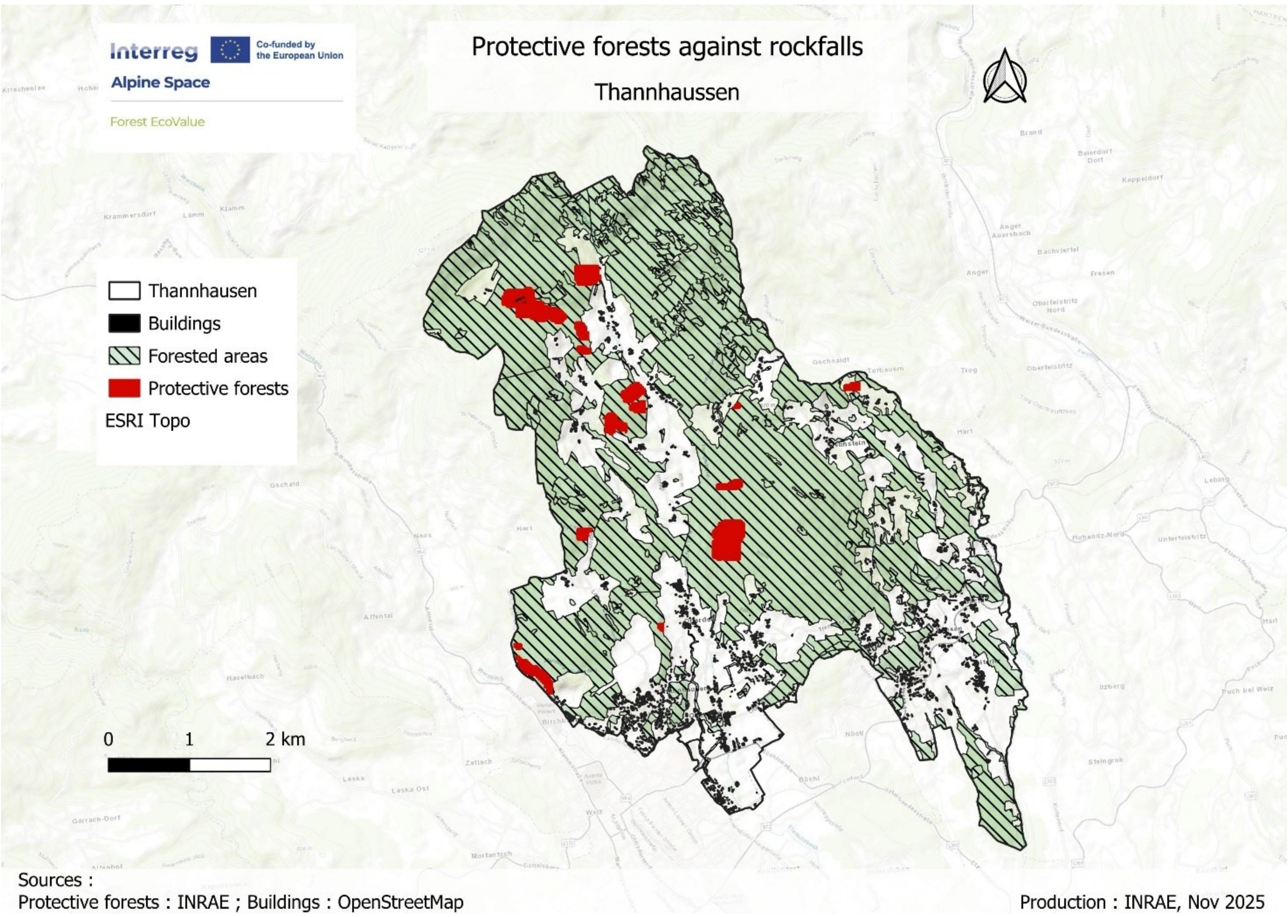
- FES 2: map of volume standing timber (timber production service)



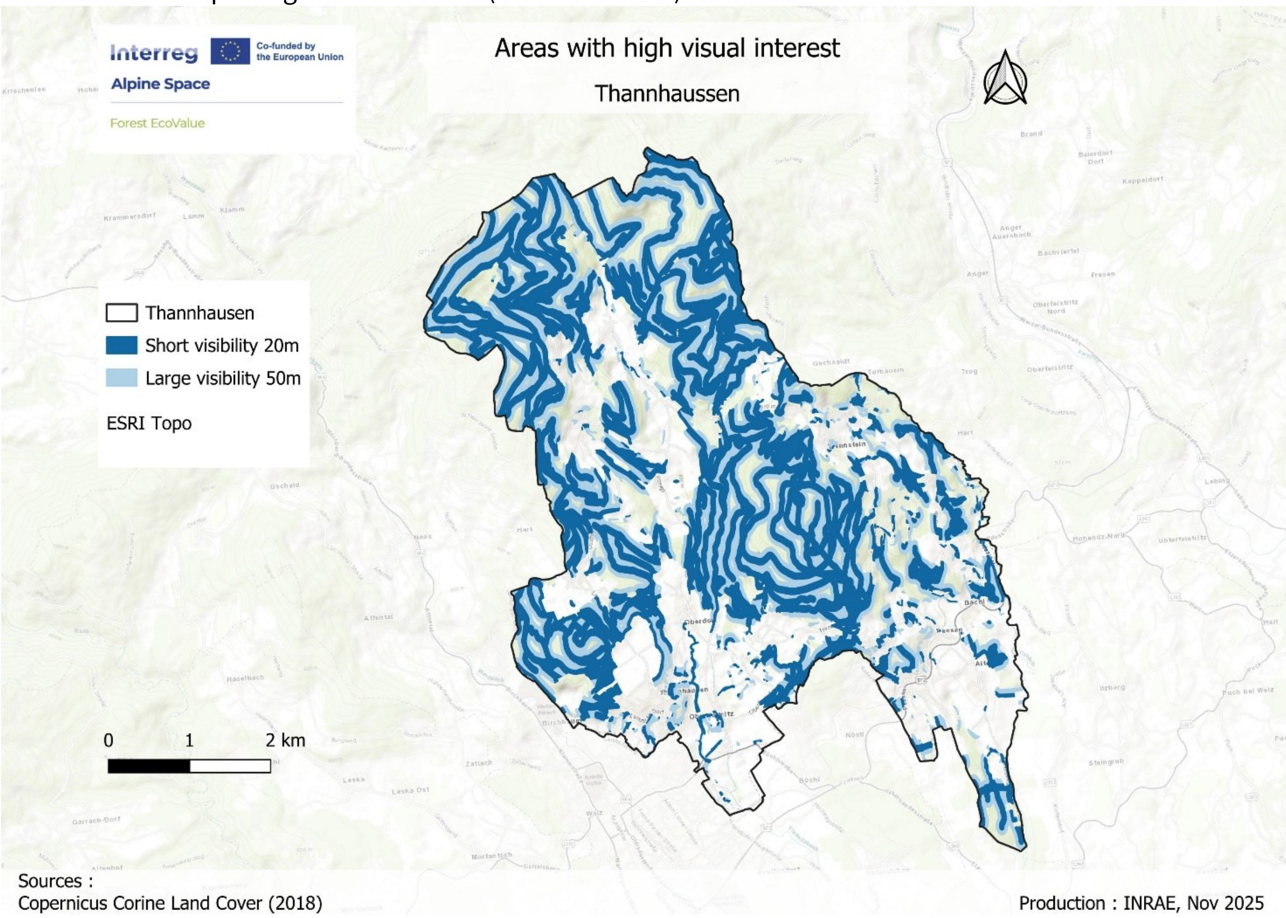
- FES3: map of carbon storage in forest areas (regulation service)



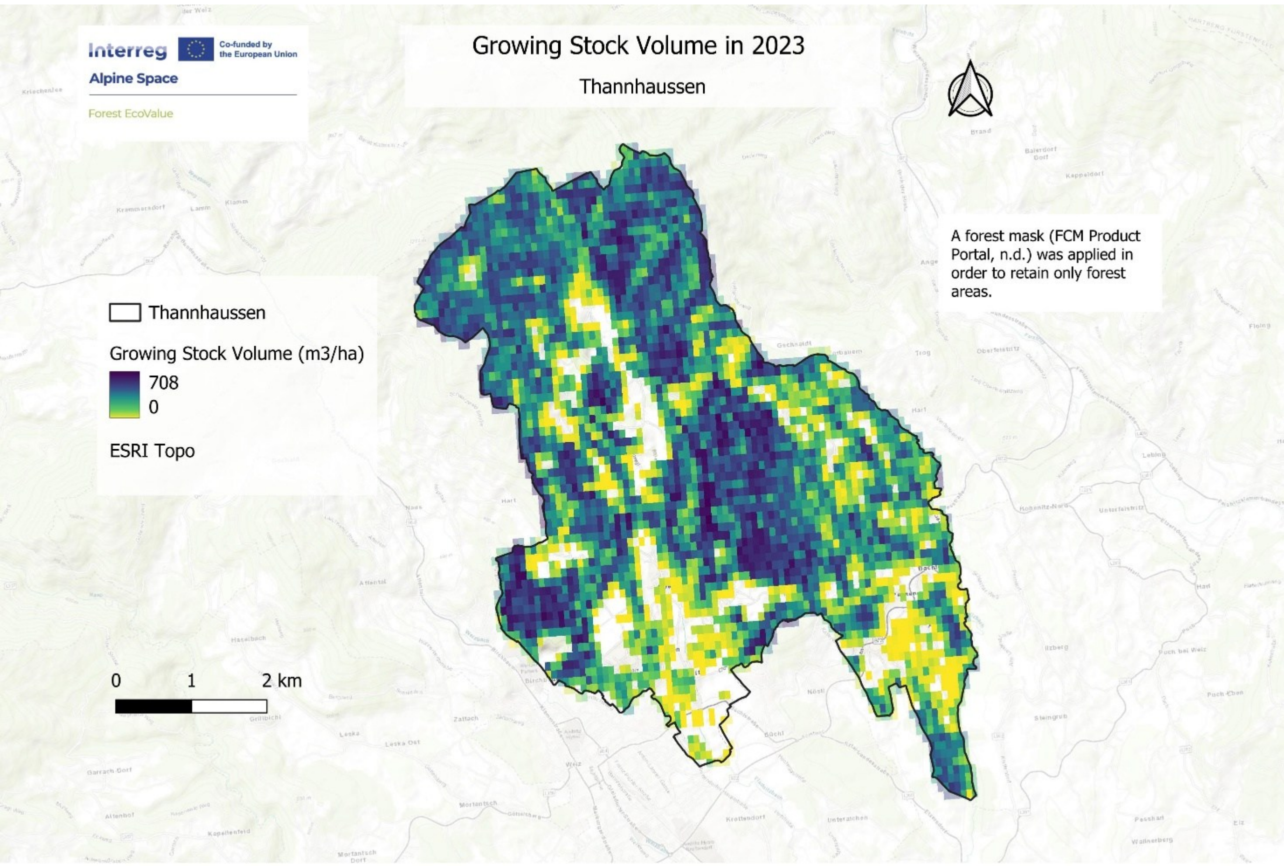
- FES4: map of protective forest against rockfall risks (regulation service)



- FES 5: map of high visual interest (cultural service)



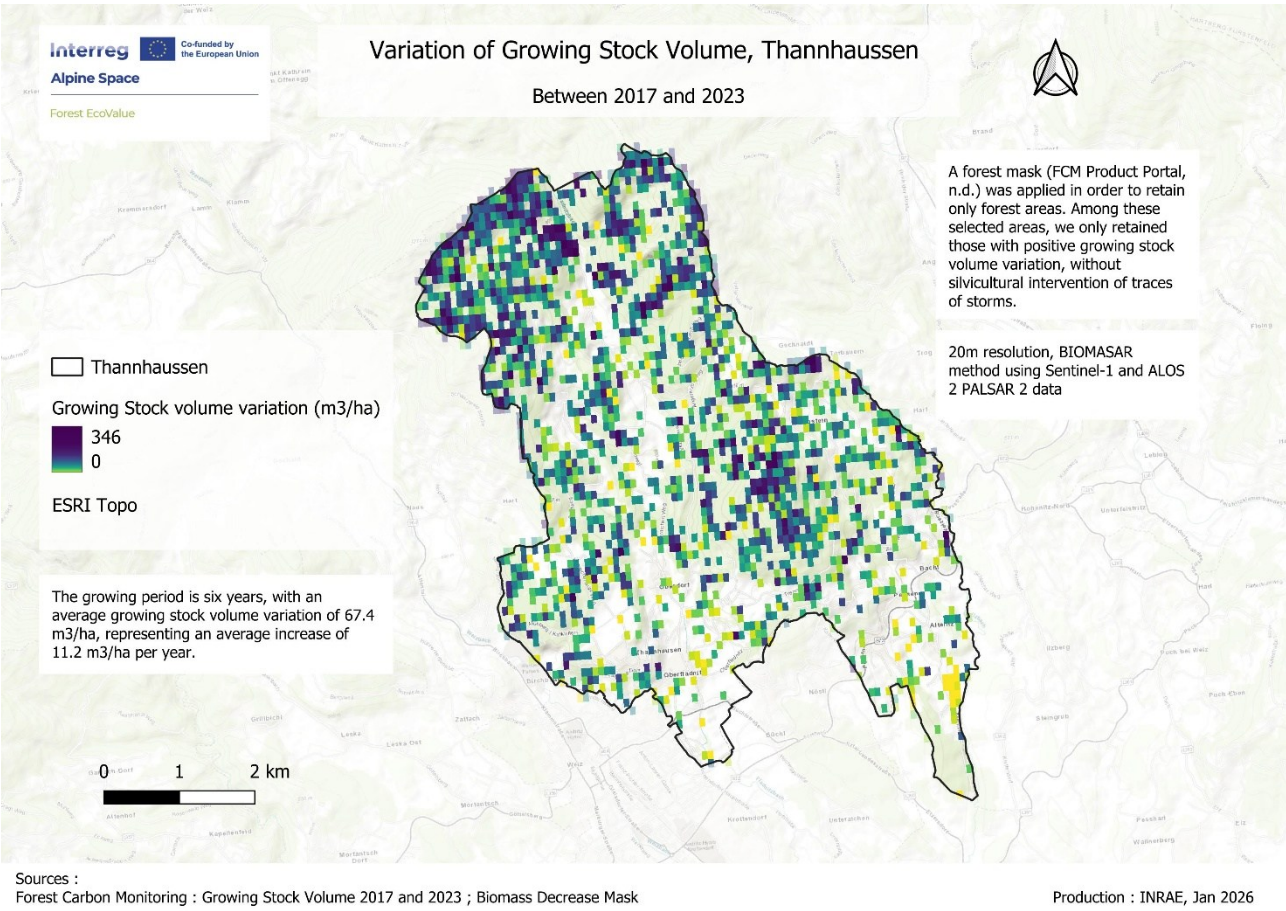
- FES 6: map of growing stock volume (regulation and support service)



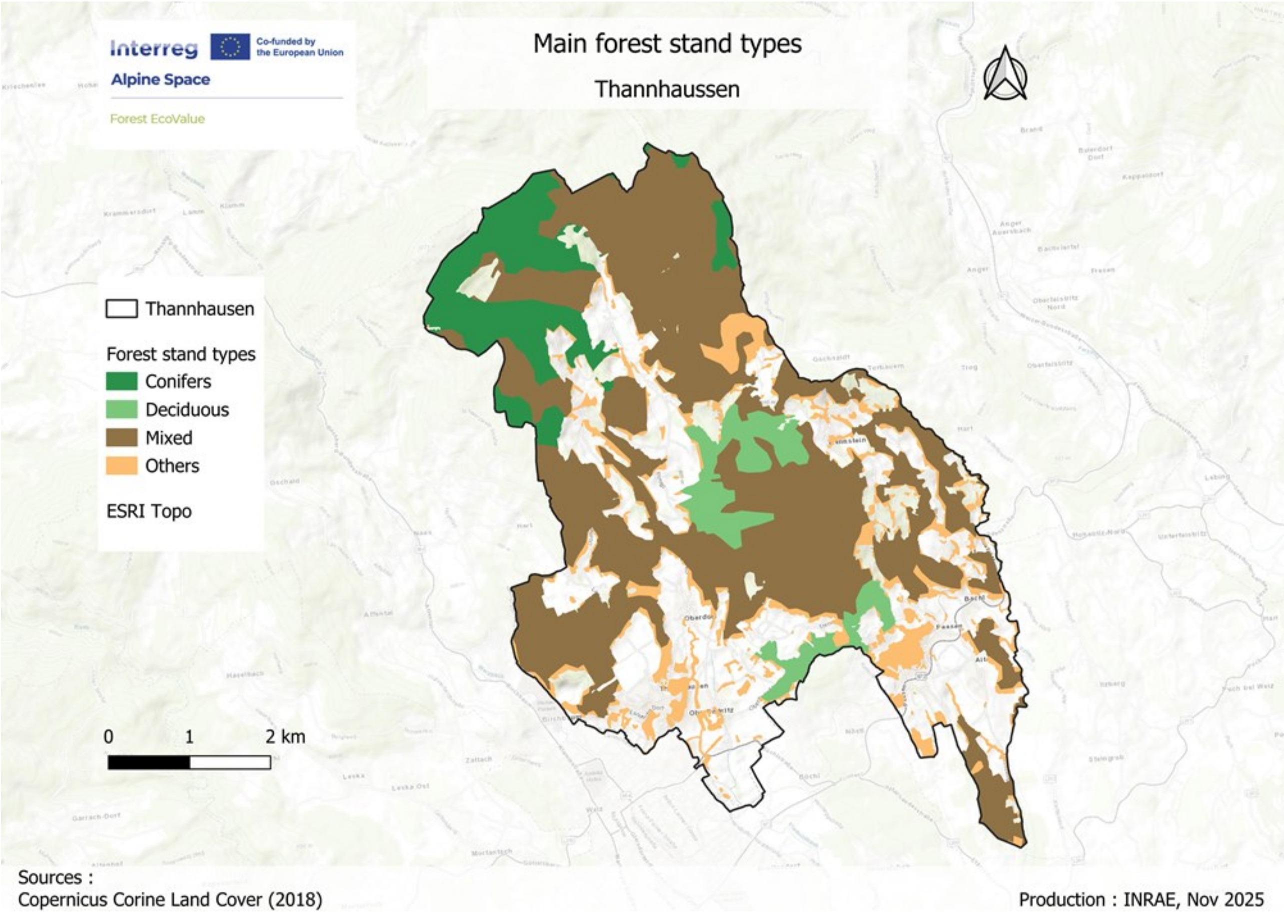
Sources :
Forest Carbon Monitoring : Growing Stock Volume 2023 ; Biomass Decrease Mask

Production : INRAE, Jan 2026

- FES 7: map of growing stock volume increment (regulation and support service)



- Map of main forest stand types (supporting all FESs biophysical assessment)



- *Synthesis table listing each FES with its associated indicator and value*

	Deciduous	Coniferous	Mixed
Area total (ha)	157,43	287,79	1429,75
mean Carbon stored (T/ha)	191,05	179,30	175,63
Total Carbon stored (T)	30076,86	51600,93	251104,97
mean Volume (m^3/ha)	774,37	726,75	711,87
Total Volume (m^3)	121909,33	209151,98	1017793,43
mean Growth (m^3/ha.year): high-range estimate	11,44	15,72	11,67
mean Growth (m^3/ha.year): mid-range estimate	8,79	12,08	8,97
mean Growth (m^3/ha.year): low-range estimate	7,26	9,97	7,41
Total Growth (m^3/year)	1801,57	4524,90	16691,59
Carbon sequestration (T/year): high estimate	5,44	7,47	5,55
Carbon sequestration (T/year): mid-range estimate	4,17	5,74	4,26
Carbon sequestration (T/year): low-range estimate	3,45	4,74	3,52
% of forest stands	8,40%	15,35%	76,25%

	Biodiversity	Production	Protective	Tourism
Area total (ha)	204,97	2126,66	76,35	1767,83
mean Carbon stored (T/ha)	164,97	169,44	166,70	170,85
mean Volume (m^3/ha)	668,66	686,77	675,66	692,49
mean Growth (m^3/ha.year): high-range estimate	9,30	11,56	12,71	12,22
mean Growth (m^3/ha.year): mid-range estimate	7,14	8,88	9,76	9,39
mean Growth (m^3/ha.year): low-range estimate	5,90	7,33	8,06	7,75
Carbon sequestration (T/ha.year): high-range estimate	4,42	5,49	6,04	5,81
Carbon sequestration (T/year): mid-range estimate	3,39	4,22	4,64	4,46
Carbon sequestration (T/ha.year) : low-range estimate	2,80	3,48	3,83	3,68
FES in % of the total forest area	9,64%	100,00%	3,59%	83,13%

BIODIVERSITE	Deciduous	Coniferous	Mixed
Area total (ha)	*24,89*	*5,48*	*121,10*
mean Carbon stored (T/ha)	75,35	113,68	129,81
Total Carbon stored (T)	1875,78	623,41	15718,91
mean Volume (m^3/ha)	305,41	305,41	526,13
Total Volume (m^3)	7603,04	1674,88	63712,81
mean Growth (m^3/ha.year): high-range estimate	8,13	8,13	10,12
mean Growth (m^3/ha.year): mid-range estimate	6,25	6,25	7,77
mean Growth (m^3/ha.year): low estimate	5,16	5,16	6,42
Total Growth (m^3/year)	202,44	44,60	1225,73
Carbon sequestration (T/ha.year): high-range estimate	3,86	3,86	4,81
Carbon sequestration (T/year): mid-range estimate	2,97	2,97	3,69
Carbon sequestration (T/ha.year): low-range estimate	2,45	2,45	3,05

% of forest stands	16,43%	3,62%	79,94%

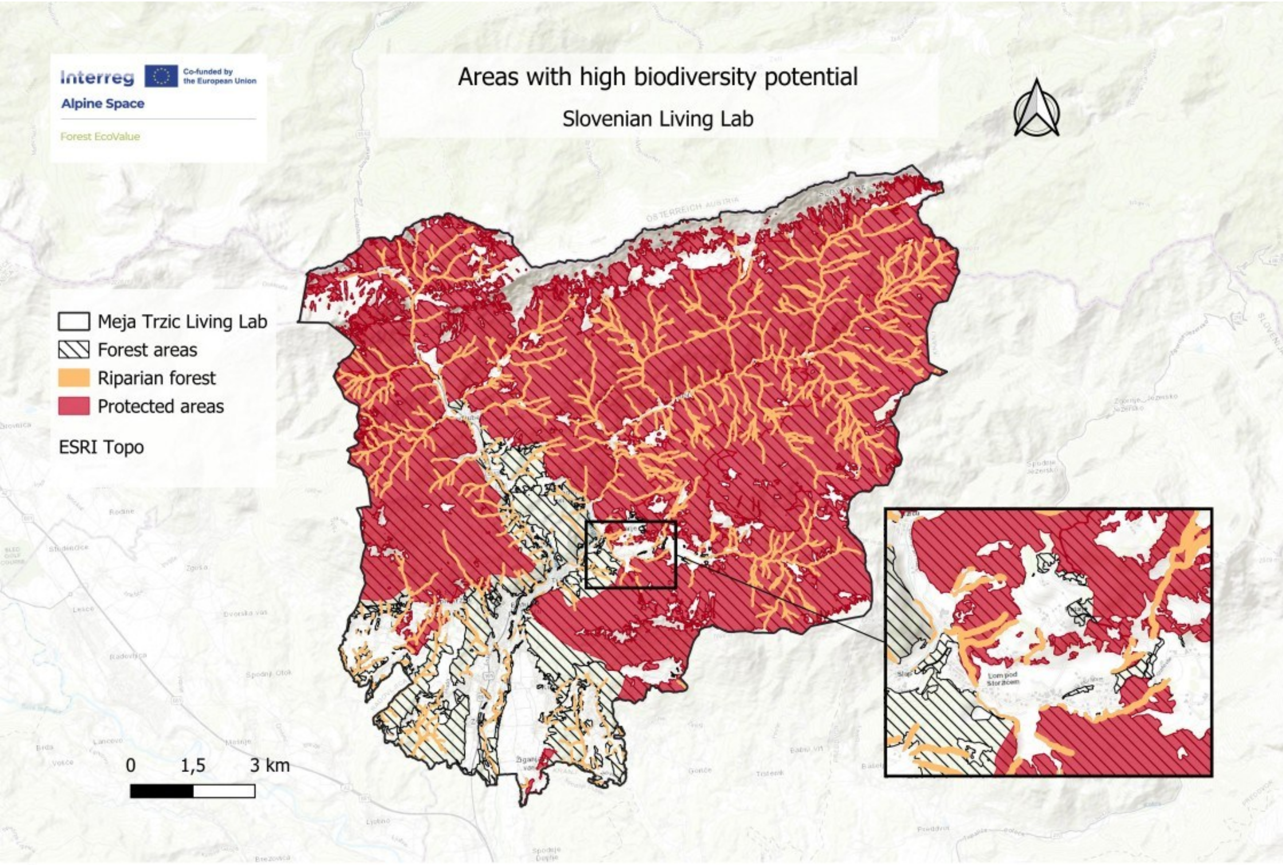
PRODUCTION	Deciduous	Coniferous	Mixed
Area total (ha)	*10,65*	*18,66*	*1427,03*
mean Carbon stored (T/ha)	67,29	110,91	132,98
Total Carbon stored (T)	716,71	2069,48	189770,72
mean Volume (m^3/ha)	272,75	321,31	456,78
Total Volume (m^3)	2905,00	5995,53	651838,16
mean Growth (m^3/ha.year): high-range estimate	14,84	12,93	14,92
mean Growth (m^3/ha.year): mid-range estimate	11,40	9,93	11,46
mean Growth (m^3/ha.year): low estimate	9,41	8,20	9,46
Total Growth (m^3/year)	158,06	241,22	21291,59
Carbon sequestration (T/ha.year): high-range estimate	7,05	6,14	7,09
Carbon sequestration (T/year): mid-range estimate	5,41	4,72	5,44
Carbon sequestration (T/ha.year): low-range estimate	4,47	3,89	4,50
% of forest stands	0,73%	1,29%	97,99%

TOURISM	Deciduous	Coniferous	Mixed
Area total (ha)	*141,13*	*259,28*	*1173,01*
mean Carbon (T/ha)	68,66	111,23	133,61
Total Carbon (T)	9690,50	1051498,64	156725,64
mean Volume (m^3/ha)	450,83	308,33	541,56
Total Volume (m^3)	63627,92	4261997,23	635249,92
mean Growth (m^3/ha.year): high-range estimate	14,76	14,38	12,05
mean Growth (m^3/ha.year): mid-range estimate	11,34	11,05	9,26
mean Growth (m^3/ha.year): low estimate	9,36	9,12	7,65
Total Growth (m^3/year)	2083,02	198795,23	14138,74
Carbon sequestration (T/ha.year): high-range estimate	7,01	6,83	5,73
Carbon sequestration (T/year): mid-range estimate	5,38	5,25	4,40
Carbon sequestration (T/ha.year): low-range estimate	4,45	4,33	3,63
% of forest stands	8,97%	28,71%	74,55%

PROTECTIVE	Deciduous	Coniferous	Mixed
Area total (ha)	*10,65*	*18,66*	*41,34*
mean Carbon (T/ha)	41,99	123,90	74,13
Total Carbon (T)	447,26	101270,23	3064,66
mean Volume (m^3/ha)	170,21	502,20	122,31
Total Volume (m^3)	1812,86	410474,54	5056,69
mean Growth (m^3/ha.year): high-range estimate	16,52	10,96	12,55
mean Growth (m^3/ha.year): mid-range estimate	12,69	13,18	11,53
mean Growth (m^3/ha.year): low estimate	10,48	10,88	7,96
Total Growth (m^3/year)	175,97	19202,96	518,73
Carbon sequestration (T/ha.year): high-range estimate	7,85	8,15	5,96
Carbon sequestration (T/year): mid-range estimate	6,03	6,26	5,48
Carbon sequestration (T/ha.year): low-range estimate	4,98	5,17	3,78
% of forest stands	15,07%	23,86%	58,52%

5.6LL5: Karavanke Mountains, municipality Tržič

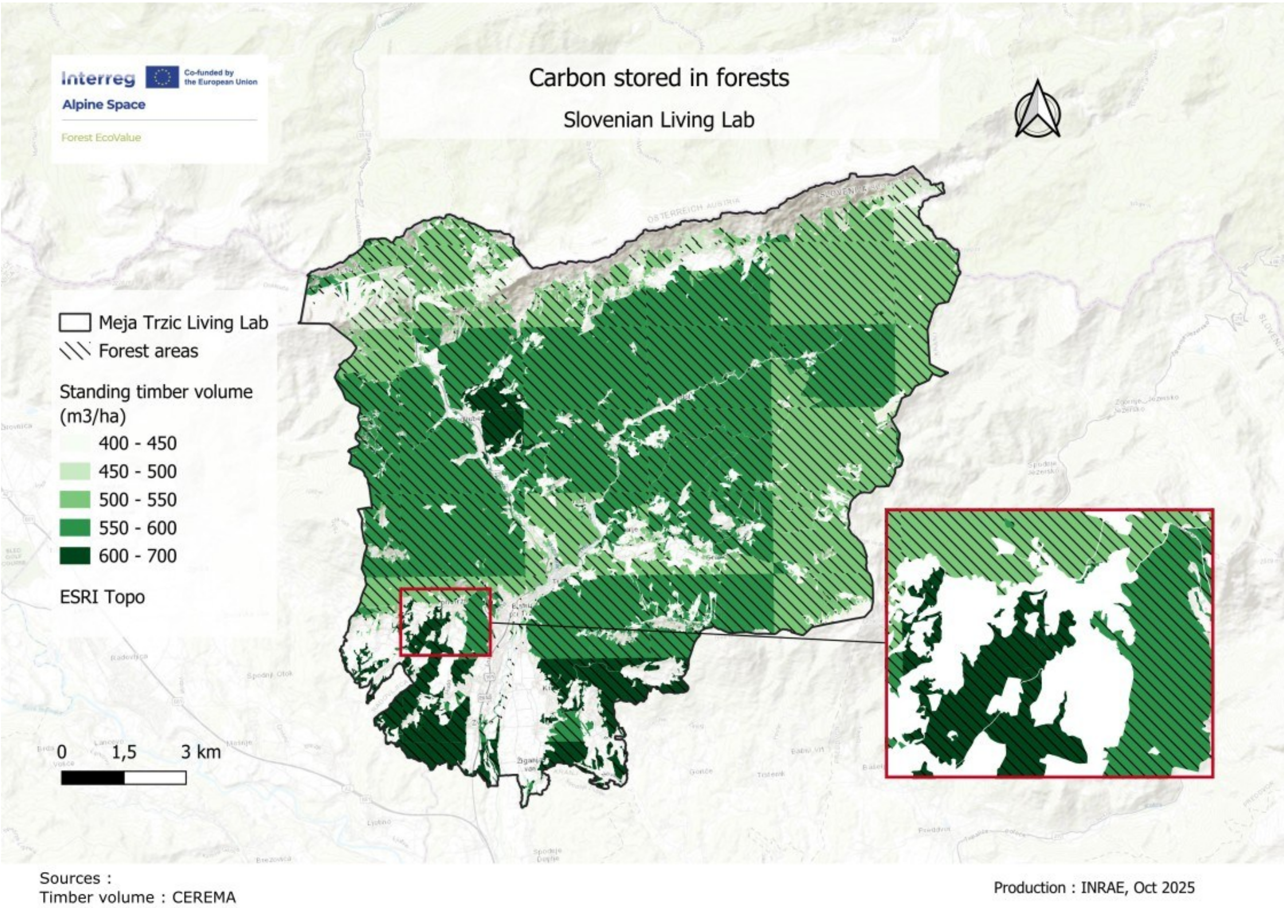
- FES1: map of forest areas with high biodiversity and habitat support potential (support service)



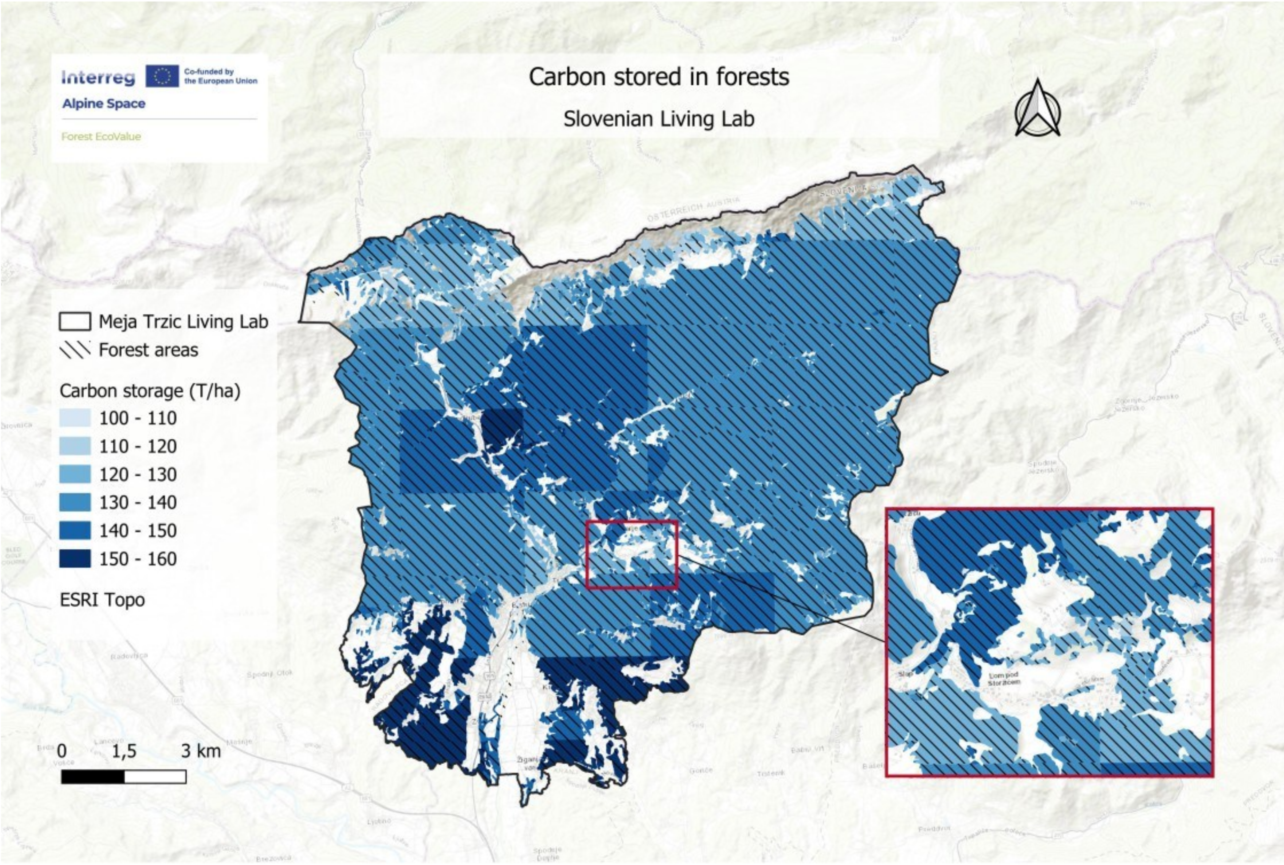
Sources :
Rivers : Slovenia Forest Service ; Protected forests (Natura 2000) : European Environment Agency

Production : INRAE, Oct 2025

- FES2: map of volume standing timber (timber production service)



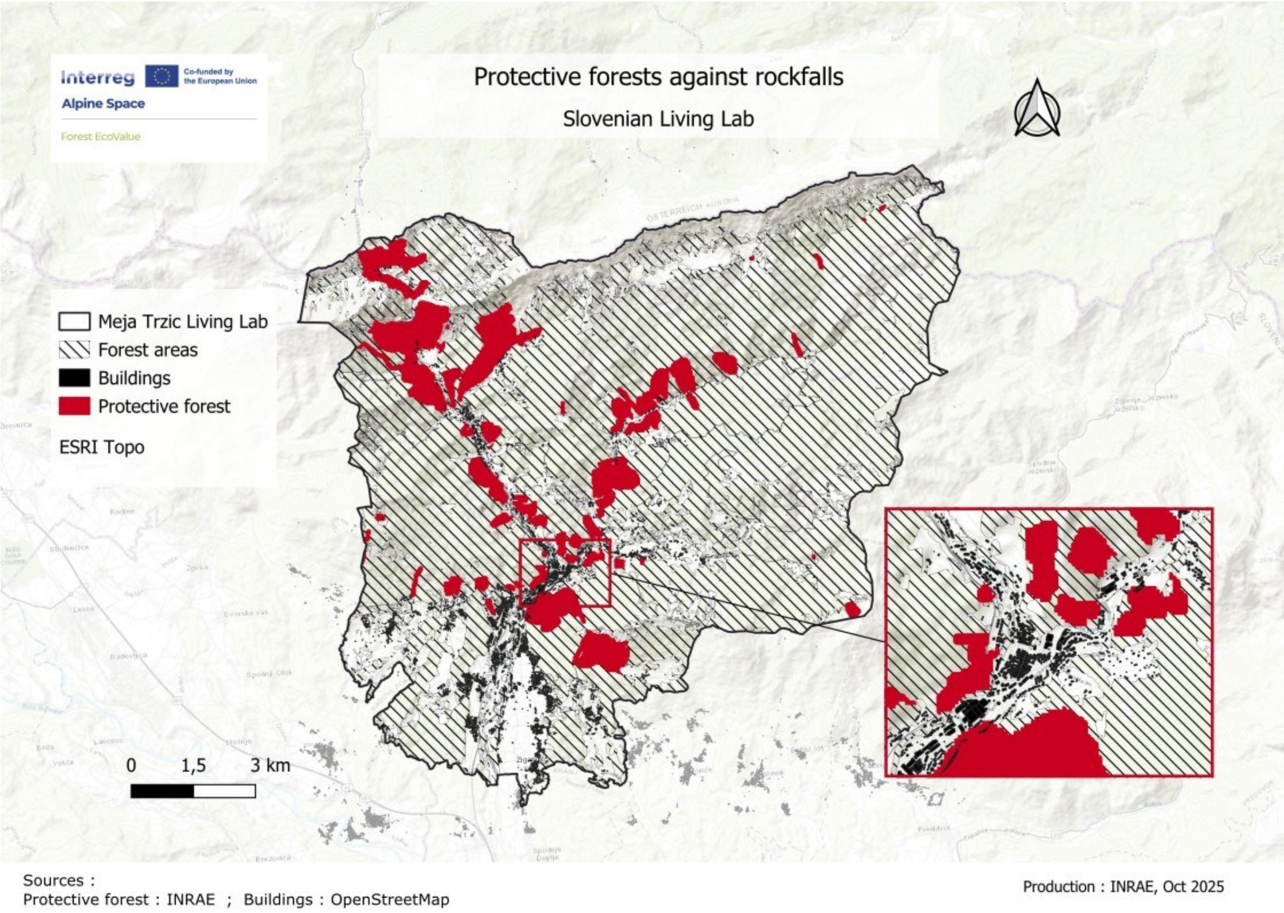
- FES3: map of carbon storage in forest areas (regulation service)



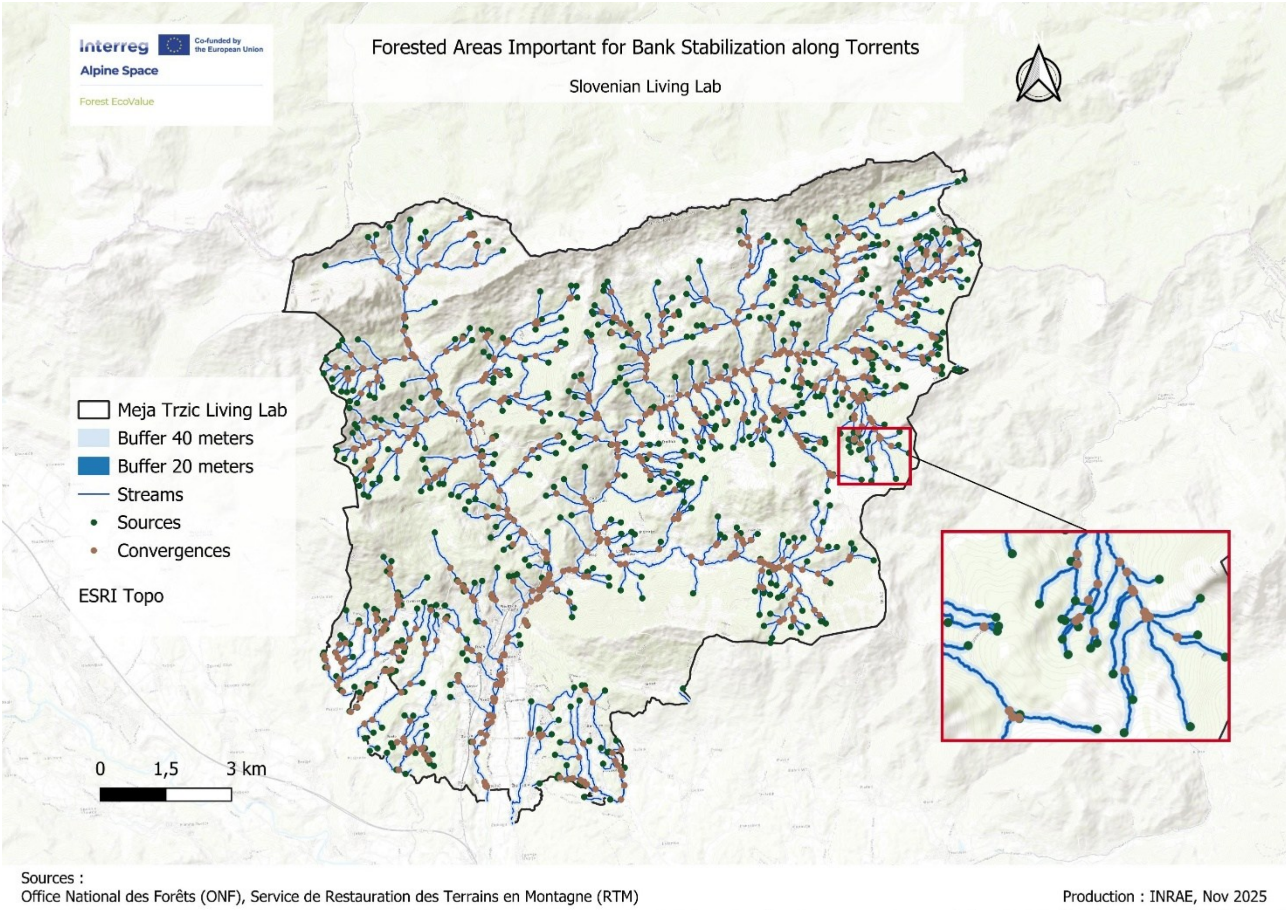
Sources :
Timber volume : CEREMA

Production : INRAE, Oct 2025

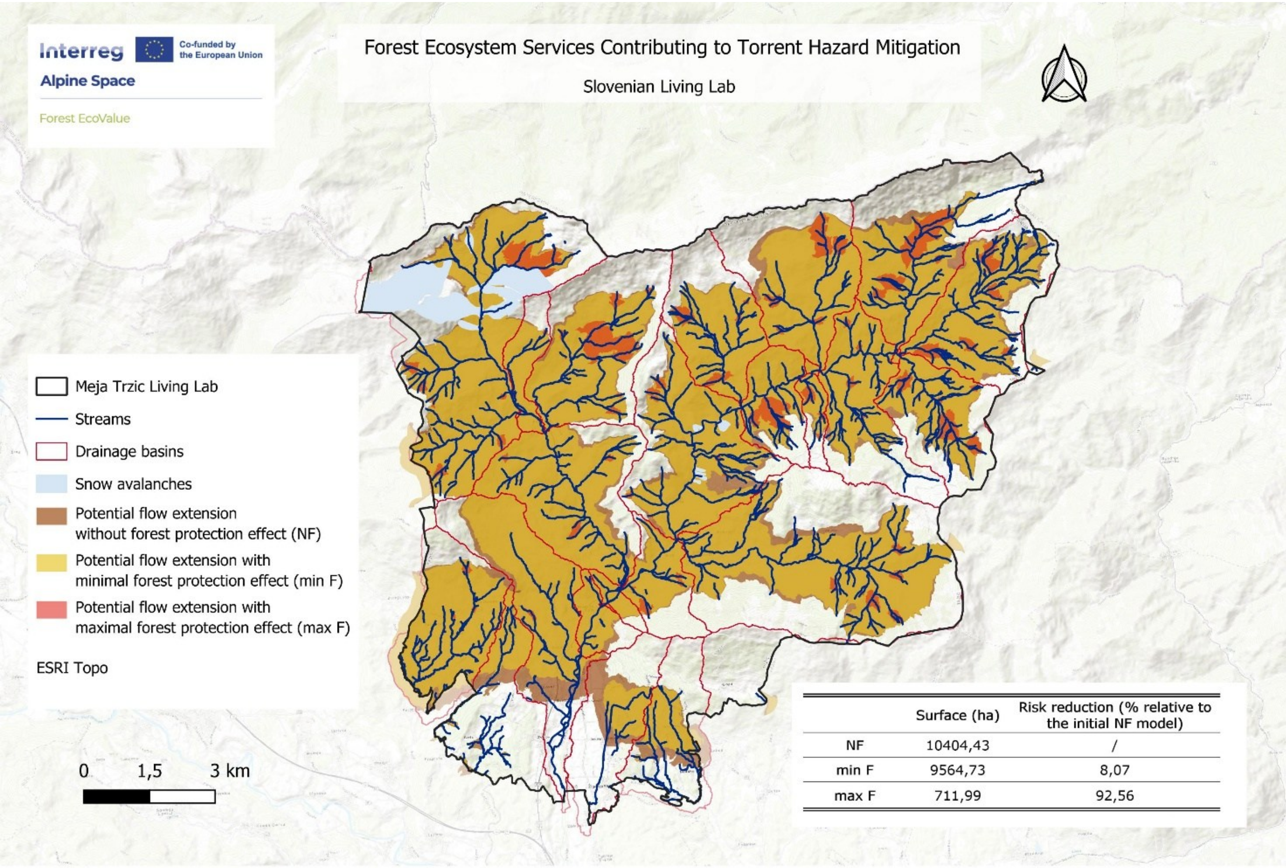
- FES4: map of protective forest (regulation service)
    - Protective forest against rockfalls



- Forest area of high relevance for river/torrent bank stabilization



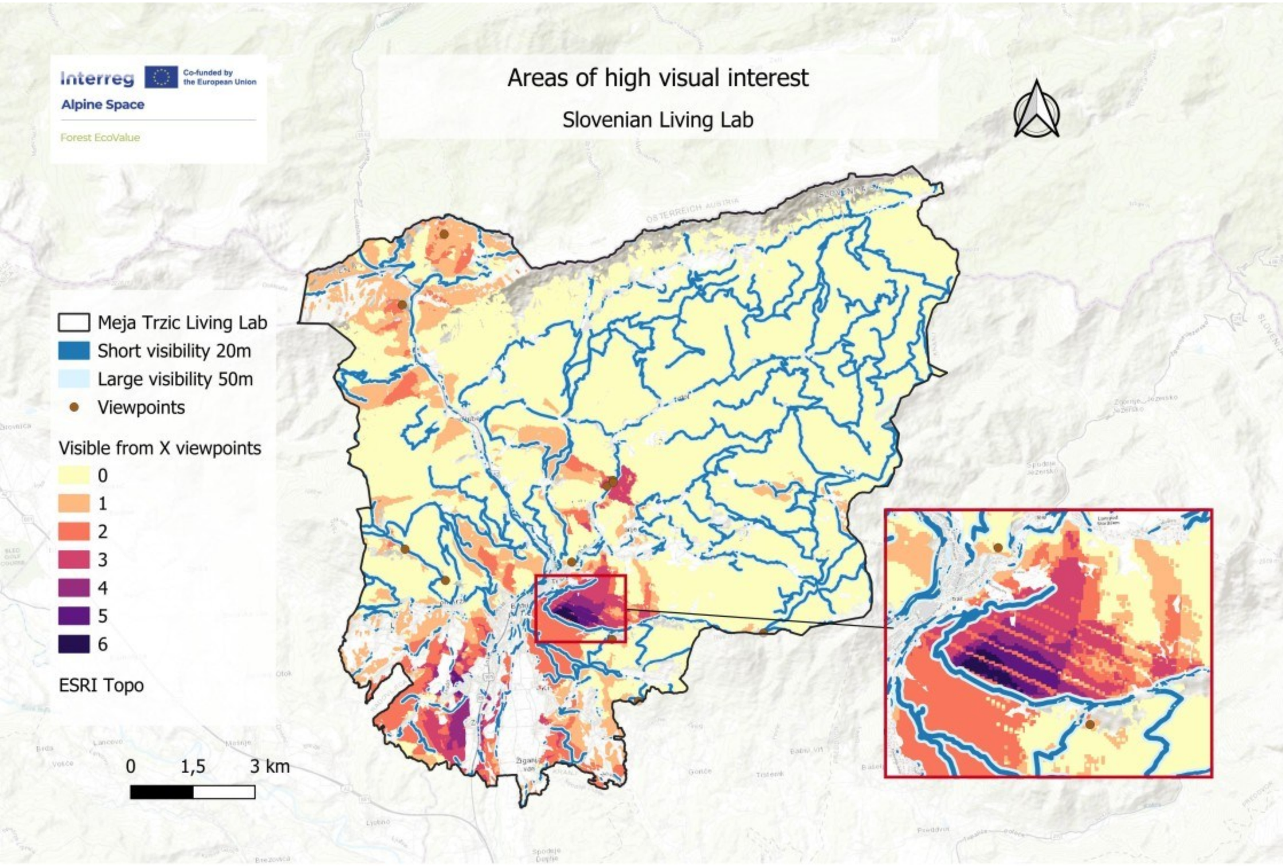
- Forest area of high relevance for protection against torrential risks



Sources :
MassMov modelisation, INRAE

Production : INRAE, Nov 2025

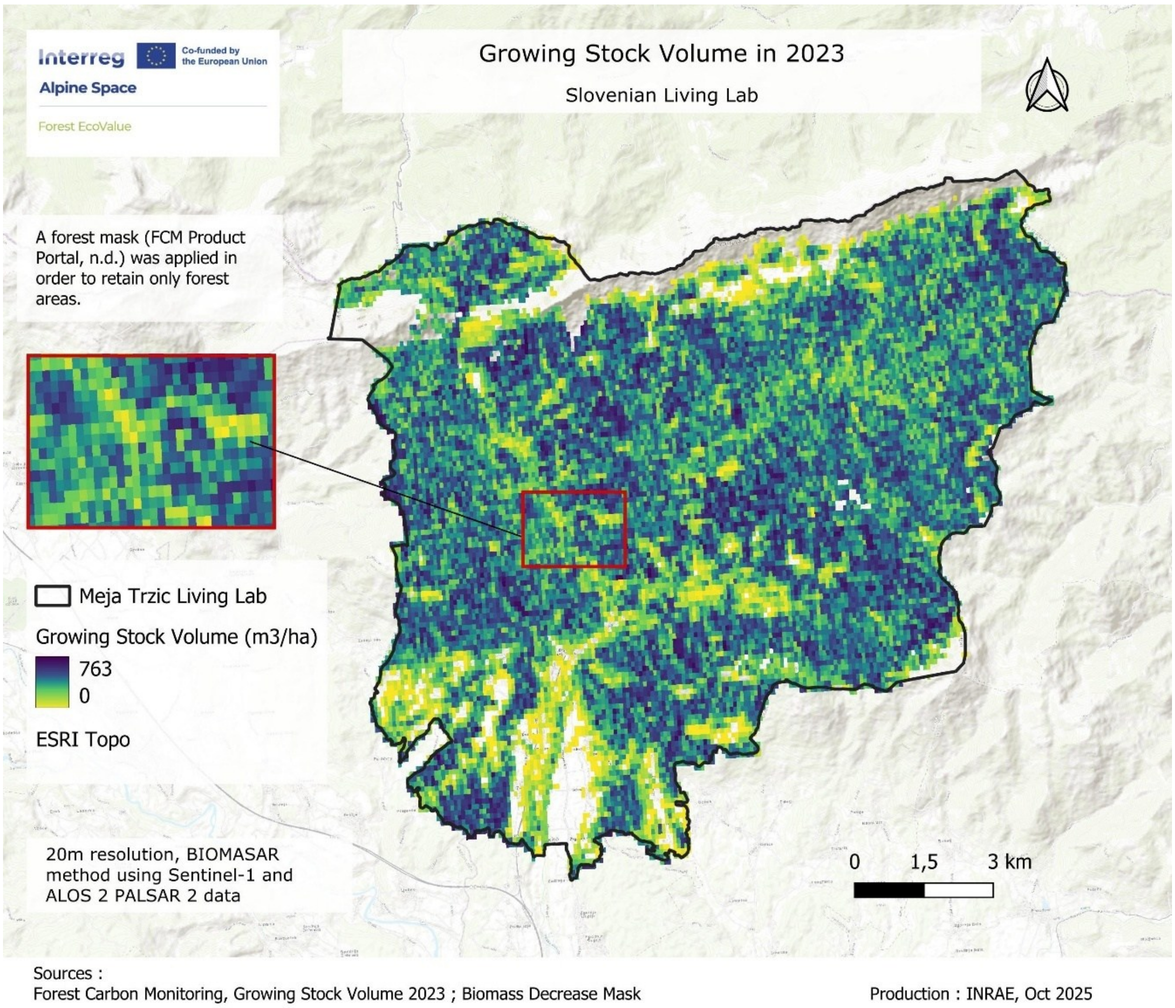
- FES 5: map of high visual interest (cultural service)



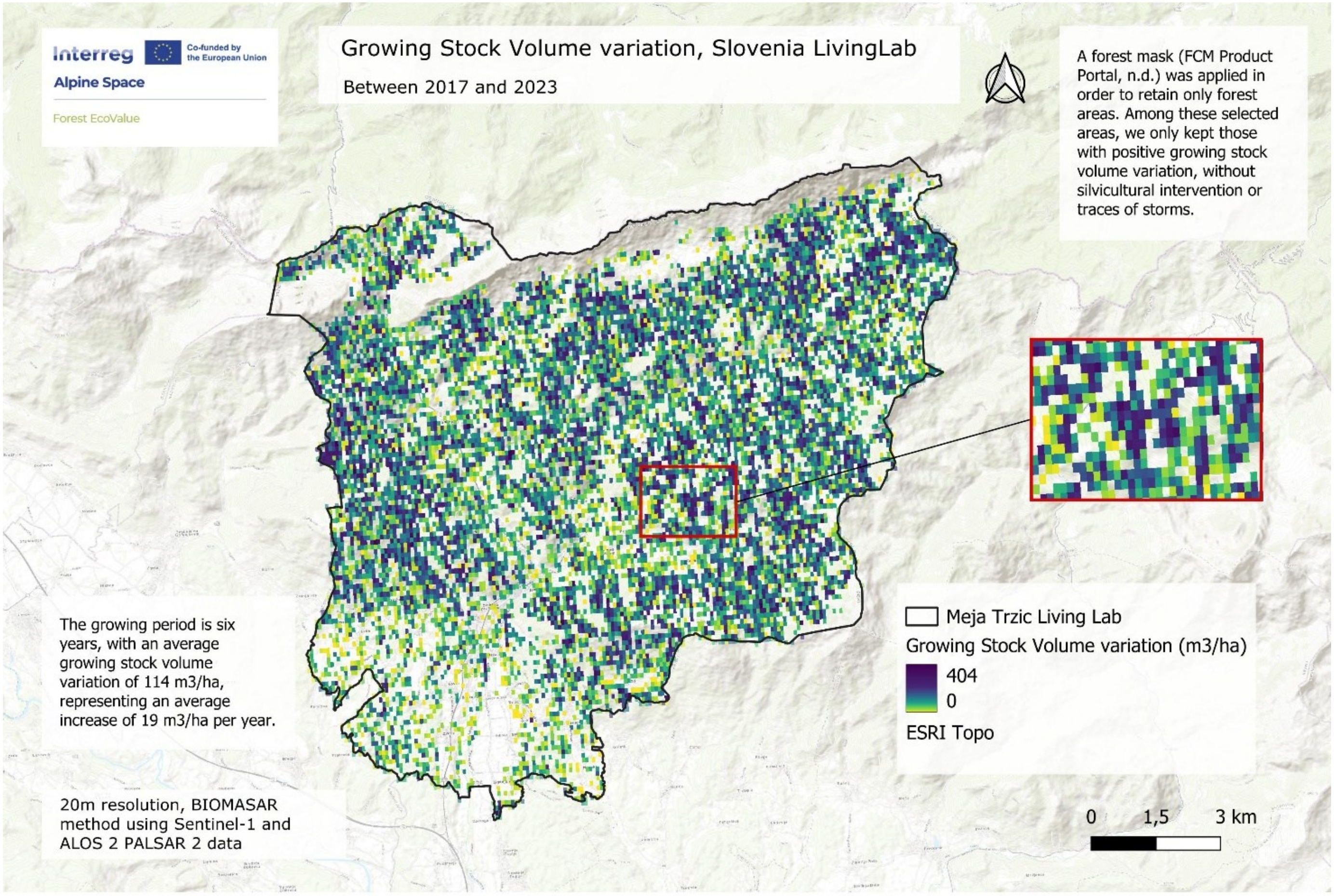
Sources :
Viewpoints : OpenStreetMap Roads : Slovenia Forest Service

Production : INRAE, Oct 2025

- FES 6: map of growing stock volume (regulation and support service)



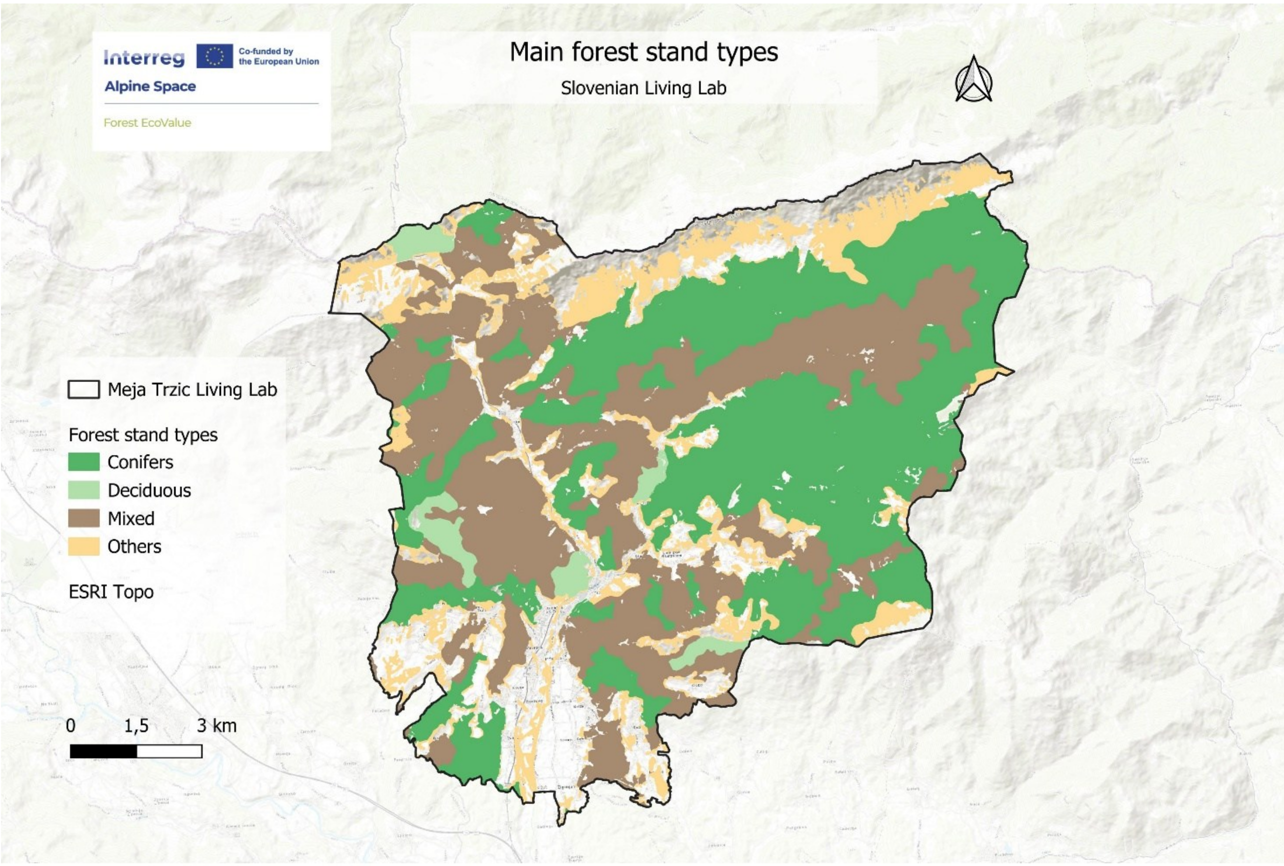
- FES 7: map of growing stock volume increment (regulation and support service)



Sources :
Forest Carbon Monitoring, Growing Stock Volume 2017 and 2023 ; Biomass Decrease Mask

Production : INRAE, Sept 2025

- Map of main forest stand types (supporting all FESs biophysical assessment)



Sources : Copernicus Corine Land Cover (2018)
Production : INRAE, Oct 2025

- *Synthesis table listing each FES with its associated indicator and value*

	Deciduous	Coniferous	Mixed
Area total (ha)	1704,49	5494,39	4630,29
mean Carbon stored (T/ha)	131,97	135,33	137,83
Total Carbon stored (T)	224944,34	743538,77	638187,26
mean Volume (m^3/ha)	534,92	548,52	558,66
Total Volume (m^3)	911757,88	3013755,33	2586738,19
mean Growth (m^3/ha.year): high-range estimate	15,83	17,93	18,32
mean Growth (m^3/ha.year): mid-range estimate	12,15	13,77	14,07
mean Growth (m^3/ha.year): low-range estimate	10,04	11,37	11,62
Carbon sequestration (T/year): high estimate	7,52	8,52	8,70
Carbon sequestration (T/year): mid-range estimate	5,77	6,54	6,68
Carbon sequestration (T/year): low-range estimate	4,77	5,40	5,52
% of forest stands	14,41%	46,45%	39,14%

	Biodiversity	Production	Tourism
Area total (ha)	10414,44	11829,17	4414,47
mean Carbon stored (T/ha)	136,28	136,96	137,44
mean Volume (m^3/ha)	552,37	555,15	557,08
mean Growth (m^3/ha.year): high-range estimate	20,40	16,96	18,08
mean Growth (m^3/ha.year): mid-range estimate	15,67	13,03	13,88
mean Growth (m^3/ha.year): low-range estimate	12,94	10,76	11,47
Carbon sequestration (T/ha.year): high-range estimate	9,69	8,06	8,59
Carbon sequestration (T/year): mid-range estimate	7,44	6,19	6,59
Carbon sequestration (T/ha.year) : low-range estimate	6,15	5,11	5,45
FES in % of the total forest area	88,04%	100,00%	37,32%

	Protective (rockfalls)	Protective (torrents woody debris)
Area total (ha)	1180,25	2804,75
mean Carbon stored (T/ha)	125,78	105,51
mean Volume (m^3/ha)	509,84	427,67
mean Growth (m^3/ha.year): high-range estimate	19,43	19,52
mean Growth (m^3/ha.year): mid-range estimate	14,92	14,99
mean Growth (m^3/ha.year): low-range estimate	12,33	12,38
Carbon sequestration (T/ha.year): high-range estimate	9,23	9,27
Carbon sequestration (T/year): mid-range estimate	7,09	7,12
Carbon sequestration (T/ha.year) : low-range estimate	5,85	5,88
FES in % of the total forest area	9,98%	23,71%

BIODIVERSITE	Deciduous	Coniferous	Mixed
Area total (ha)	*1439,95*	*4987,51*	*3986,98*
mean Carbon stored (T/ha)	61,12	100,91	85,58
Total Carbon stored (T)	88012,19	503296,94	341199,23
mean Volume (m^3/ha)	247,74	409,02	346,87
Total Volume (m^3)	356736,28	2039993,20	1382969,08
mean Growth (m^3/ha.year): high-range estimate	18,13	20,93	20,77
mean Growth (m^3/ha.year): mid-range estimate	13,92	16,08	15,95
mean Growth (m^3/ha.year): low estimate	11,50	13,28	13,17
Carbon sequestration (T/ha.year): high-range estimate	8,61	9,94	9,87
Carbon sequestration (T/year): mid-range estimate	6,61	7,64	7,58
Carbon sequestration (T/ha.year): low-range estimate	5,46	6,31	6,26
% of forest stands	13,83%	47,89%	38,28%

PRODUCTION	Deciduous	Coniferous	Mixed
Area total (ha)	*1644,31*	*5488,83*	*4623,53*
mean Carbon stored (T/ha)	63,46	96,88	88,16
Total Carbon stored (T)	104354,81	531774,46	407605,82
mean Volume (m^3/ha)	257,24	392,69	357,33
Total Volume (m^3)	422977,14	2155420,08	1652132,26
mean Growth (m^3/ha.year): high-range estimate	17,31	19,71	20,10
mean Growth (m^3/ha.year): mid-range estimate	13,29	15,14	15,44
mean Growth (m^3/ha.year): low estimate	10,98	12,50	12,75
Carbon sequestration (T/ha.year): high-range estimate	8,22	9,36	9,55
Carbon sequestration (T/year): mid-range estimate	6,31	7,19	7,33
Carbon sequestration (T/ha.year): low-range estimate	5,22	5,94	6,06
% of forest stands	13,99%	46,69%	39,33%

PROTECTIVE rockfalls	**Deciduous**	**Coniferous**	**Mixed**
Area total (ha)	*112,61*	*215,68*	*757,36*
mean Carbon (T/ha)	61,80	78,03	97,99
Total Carbon (T)	6958,69	16829,45	74213,85
mean Volume (m^3/ha)	250,48	316,28	397,18
Total Volume (m^3)	28205,40	68214,15	300808,01
mean Growth (m^3/ha.year): high-range estimate	17,38	17,07	20,78
mean Growth (m^3/ha.year): mid-range estimate	13,35	13,11	15,96
mean Growth (m^3/ha.year): low estimate	11,03	10,83	13,18
Total Growth (m^3/year)	1957,38	3681,67	15741,29
Carbon sequestration (T/ha.year): high-range estimate	8,26	8,11	9,87
Carbon sequestration (T/year): mid-range estimate	6,34	6,23	7,58
Carbon sequestration (T/ha.year): low-range estimate	5,24	5,14	6,26
% of forest stands	10,37%	19,87%	69,76%

Total road length within the living lab area (km)	307
Road length protected by protection forests (km)	22,4
Percentage of roads protected by forest (%)	7,30%

PROTECTIVE (torrents woody debris)	**Deciduous**	**Coniferous**	**Mixed**
Area total (ha)	*733,18*	*1773,30*	*1907,99*
mean Carbon (T/ha)	101,56	96,24	85,95
Total Carbon (T)	74463,43	170658,62	163982,89
mean Volume (m^3/ha)	411,66	390,08	348,36
Total Volume (m^3)	301819,64	691723,74	664665,27
mean Growth (m^3/ha.year): high-range estimate	12,97	19,79	20,22
mean Growth (m^3/ha.year): mid-range estimate	9,96	15,20	15,53
mean Growth (m^3/ha.year): low estimate	8,23	12,56	12,82
Carbon sequestration (T/ha.year): high-range estimate	6,16	9,40	9,60
Carbon sequestration (T/year): mid-range estimate	4,73	7,22	7,38
Carbon sequestration (T/ha.year): low-range estimate	3,91	5,96	6,09
% of forest stands	16,61%	40,17%	43,22%

PROTECTIVE Torrential risk: total forested concerned area (TFCA)	Deciduous	Coniferous	Mixed
Area total (ha)	*213,89*	*3657,23*	*3472,60*
mean Carbon (T/ha)	25,47	94,05	88,68
Total Carbon (T)	5446,84	343952,45	307942,00
mean Volume (m^3/ha)	103,22	381,20	359,43
Total Volume (m^3)	22077,45	1394128,62	1248168,95
mean Growth (m^3/ha.year): high-range estimate	20,32	20,56	20,21
mean Growth (m^3/ha.year): mid-range estimate	15,61	15,79	15,52
mean Growth (m^3/ha.year): low estimate	12,89	13,04	12,82
Total Growth (m^3/year)	4346,79	75206,06	70169,88
Carbon sequestration (T/ha.year): high-range estimate	9,65	9,77	9,60
Carbon sequestration (T/year): mid-range estimate	7,41	7,50	7,37
Carbon sequestration (T/ha.year): low-range estimate	6,12	6,20	6,09
% of forest stands	2,91%	49,80%	47,29%

PROTECTIVE Torrential risk: Min PFE	Deciduous	Coniferous	Mixed
Area total (ha)	*112,61*	*215,68*	*757,36*
mean Carbon (T/ha)	61,80	78,03	97,99
Total Carbon (T)	6958,69	16829,45	74213,85
mean Volume (m^3/ha)	250,48	316,28	397,18
Total Volume (m^3)	28205,40	68214,15	300808,01
mean Growth (m^3/ha.year): high-range estimate	17,38	17,07	20,78
mean Growth (m^3/ha.year): mid-range estimate	13,35	13,11	15,96
mean Growth (m^3/ha.year): low estimate	11,03	10,83	13,18
Total Growth (m^3/year)	1957,38	3681,67	15741,29
Carbon sequestration (T/ha.year): high-range estimate	8,26	8,11	9,87
Carbon sequestration (T/year): mid-range estimate	6,34	6,23	7,58
Carbon sequestration (T/ha.year): low-range estimate	5,24	5,14	6,26
% of forest stands	10,37%	19,87%	69,76%

PROTECTIVE Torrential risk: Max PFE	Deciduous	Coniferous	Mixed
Area total (ha)	*3,37*	*362,88*	*184,21*
mean Carbon (T/ha)	25,47	75,30	36,23
Total Carbon (T)	85,73	27324,04	6673,46
mean Volume (m^3/ha)	103,22	305,20	146,84
Total Volume (m^3)	347,49	110751,43	27049,25
mean Growth (m^3/ha.year): high-range estimate	5,69	21,00	4,62
mean Growth (m^3/ha.year): mid-range estimate	4,37	16,13	3,55
mean Growth (m^3/ha.year): low estimate	3,61	13,32	2,93
Total Growth (m^3/year)	19,16	7619,88	851,79
Carbon sequestration (T/ha.year): high-range estimate	2,70	9,97	2,20
Carbon sequestration (T/year): mid-range estimate	2,08	7,66	1,69
Carbon sequestration (T/ha.year): low-range estimate	1,71	6,33	1,39
% of forest stands	0,61%	65,92%	33,47%

5.7 Validation of large-scale biophysical assessments of FES using locally available data

Several studies have been conducted for evaluating the robustness of our large-scale results by comparing them with local and national data.

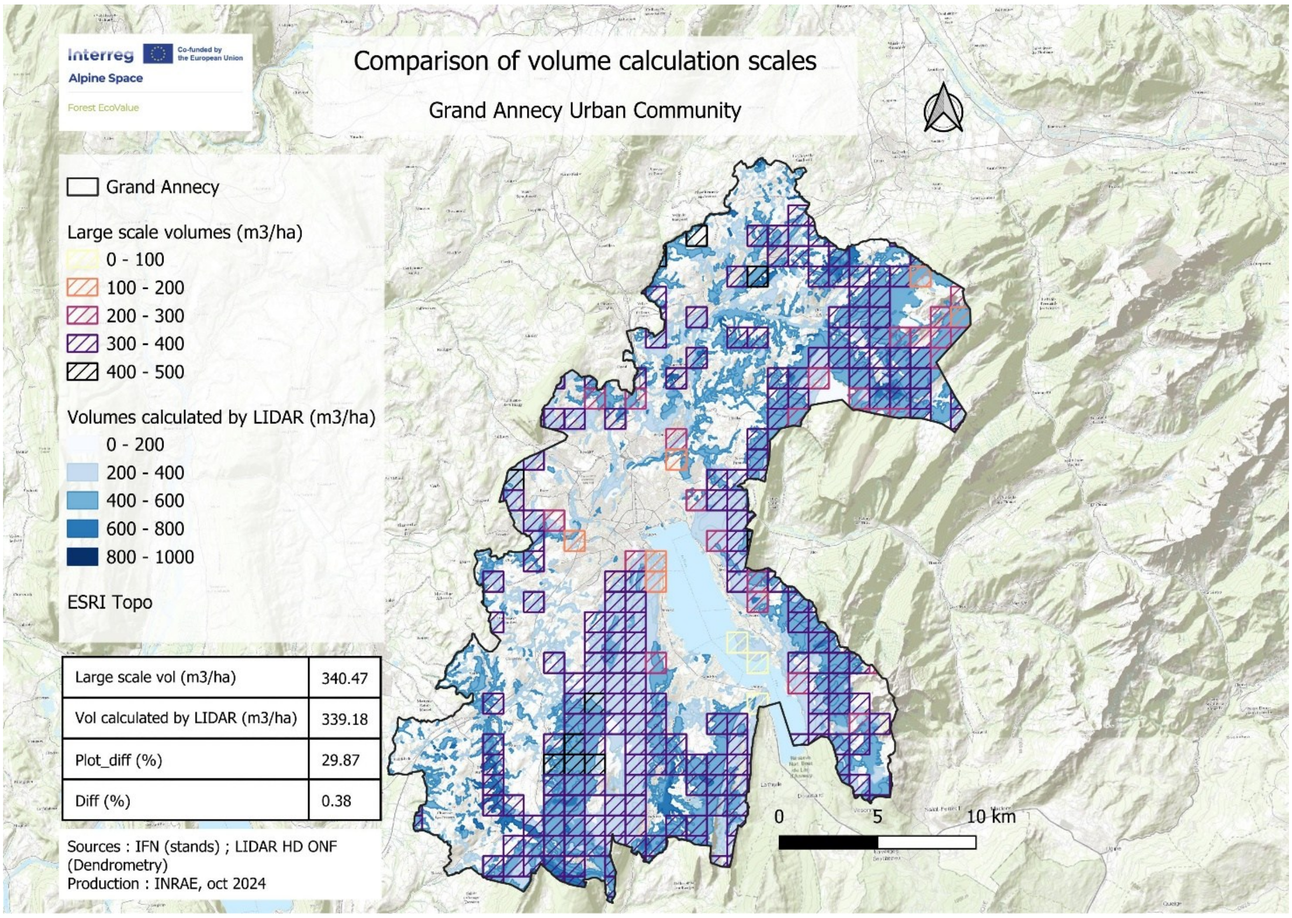
For Germany, published annual increment values range from 9.4 to 11.2 m^3/ha·yr. This aligns well with the low- and mid-range evaluations (test site [9.64; 11.67], the entire living lab [9.76; 11.84]), with error rates of : for the test site +2.56% and +4.23%, respectively, and for the entire Living Lab +3.99% and +5.67%, respectively.

For Slovenia, published increments range from 7.4 to 7.9 m^3/ha.yr, consistent with the very low- and low-range evaluations (8.18 m^3/ha.yr). The error rates at the bounds are +3.50% and +10.50%; we therefore recommend using the very low-range estimate.

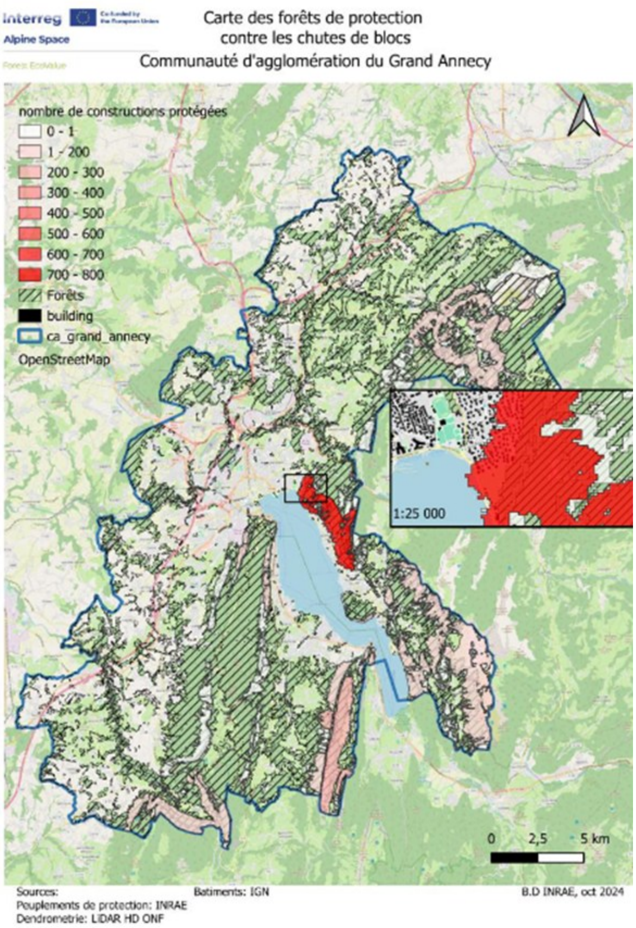
In Austria, the published annual increment for production forests is 11.89 m^3/ha.yr, close to the mid-range estimate of 11.47 m^3/ha.yr (error rate: -3.53%) for the Graz pilot area (total area of 67367.42 ha) and close to the high-range estimate of 11.56 m^3/ha.yr (error rate: -2.78%) for the Thannhausen pilot area (total area of 1874,97 ha).

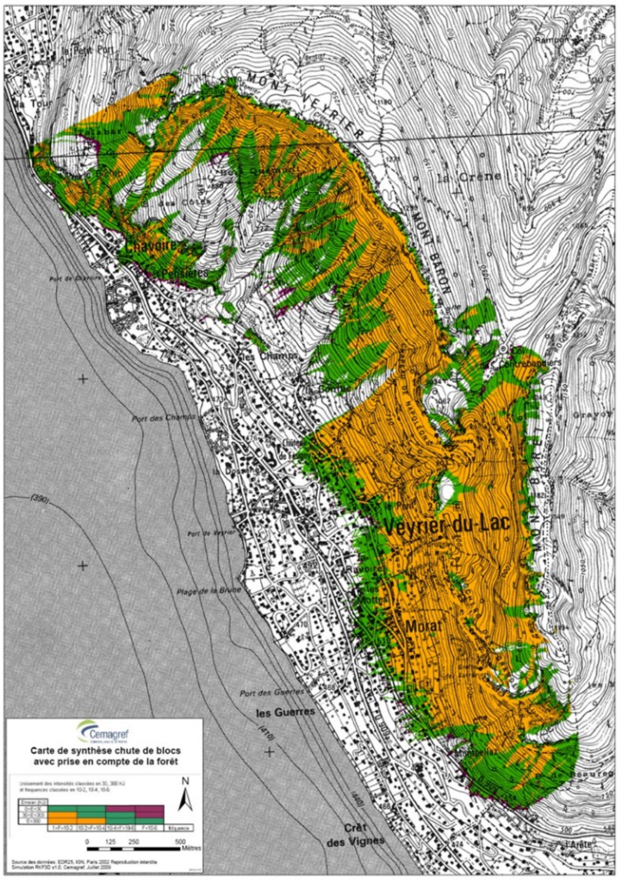
For Italian broadleaf forests, reported data indicate an average increment of 6 m^3/ha.yr and a mean volume of 200–500 m^3/ha for beech forests, and 8 m^3/ha.yr with 200–400 m^3/ha for chestnut forests. These values agree with the high-range evaluation (7.5 m^3/ha.yr; 429.4 m^3/ha) for all broadleaf stands combined.

In France, the National Forest Office conducted a dendrometric inventory using very high-resolution LiDAR (≈10 points/m^2) to produce a 20×20 m grid inventory map. In the Grand Annecy area, the total mean volume per hectare for all stand types is 340.47 m^3/ha, compared with 339.18 m^3/ha from LiDAR data (error: 0.38%). The published mean annual increment is 5.4 m^3/ha.yr, close to the high-range estimate of 5.11 m^3/ha.yr (error: 5.41%).



Finally, comparing the protection forest map with the Natural Hazards Prevention Plan (PPRn) map showed that the large-scale data accurately identifies the same most exposed area as that the ones covered by the PPRn.





In conclusion, given the quality of the input data used, it is possible to determine the most robust type of estimation to apply for each country. For France and Italy, the high-range estimation is recommended; for Germany and Austria, the mid-range evaluation is suggested; and for Slovenia, the very low-range estimation should be used. This variation in estimation type follows a west-to-east geographical gradient, which very likely reflects a drift in the quality of the satellite data.

Appendix 1: How to assess torrential hazard protection forest ecosystem service?

The methodology proposed and implemented in the Forest EcoValue project

River systems represent a primary source of natural hazards, with flooding being the dominant process. Assessing flood-related risks requires an accurate mapping of waterways, which necessitates detailed field surveys to ensure reliable representation of the river network.

Flood events are typically catastrophic in nature; however, they may both trigger and be triggered by other hazard processes, or act in combination with additional risks. In this study, a multi-hazard framework was therefore adopted.

As a first step, avalanche paths terminating in river channels were mapped. Potential avalanche release areas were defined based on expert judgment. Using these expert-based release zones, avalanche propagation was simulated with the FlowPy model (freely available via https://docs.avaframe.org/en/latest/), in combination with a Digital Elevation Model (DEM) and forest cover maps. The simulations identified locations where avalanches may reach river channels and potentially form temporary dams. The sudden failure of such dams could generate impulse waves, thereby increasing flood hazard. In addition, avalanche debris transported within the river channel may contribute to the formation of logs jam, particularly at bridges and other hydraulic structures.

The transport of large woody debris by rivers during flood events constitutes an additional source of hazard. To address this process, a Python-based buffering tool, to be integrated by April 2026 into the Web-atlas of the Interreg Alpine Space project MOSAIC, was developed to delineate areas where trees may represent a potential source of large-woody debris recruitment during catastrophic floods. The underlying assumption is that trees likely to be mobilized originate predominantly from upslope areas within a distance proportional to their height. Default threshold distances are set to 20 m upslope (high-probability source areas, corresponding to the average tree height in the study area) and 40 m upslope (lower-probability source areas). These distances are fully user-configurable. The tool integrates the user-selected river network with a DEM to compute true terrain-based (on-slope) distances, thereby accounting for topographic gradients and avoiding the limitations inherent to simple planimetric buffer approaches.

Finally, the impact of flooding itself may be mitigated by forest cover. A first-order proxy for this attenuation effect was assessed using the mass-movement model currently under development, MASSMOV. The model was applied using the upstream points (springs) of rivers and streams as initiation data for the propagation area, and under three contrasting scenarios:

1. No forest effect, with no additional friction applied;
2. Moderate forest effect, corresponding to 50% efficiency and representative of average observed friction values;
3. Maximum forest effect, corresponding to the highest friction values reported in the literature.

For a study site, the identification of upstream points can be carried out through field inventory work and/or by using the drainage basin outlines associated with each of the identified and mapped streams. This work of defining the drainage basins is greatly facilitated by the use of a GIS. Two step-by-step guides for using QGIS are provided below

Massmov - Gravitational mass movement propagation model

1. GENERAL OVERVIEW

MASSMOV is a modeling system developed to simulate the propagation of gravitational mass movements (avalanches and rockfalls) on three-dimensional terrain. The model uses a numerical approach based on topographic analysis and propagation profile characterization to predict potential impact zones of these hazardous natural phenomena.

2. MODEL OBJECTIVES

The model aims to:

- Simulate the spatial propagation of gravitational mass movements from defined initiation points
- Determine potential impact zones (reachable areas)
- Calculate risk indicators based on geomorphological criteria
- Produce regulatory zoning maps (red, blue, and white zones)
- Enable batch processing for simultaneous analysis of multiple sites

3. INPUT DATA

The model relies on three main types of data:

3.1. Digital Elevation Model (DEM)

- Format: Georeferenced GeoTIFF
- Raster representation of topography (regular grid of elevations)
- Variable resolution adapted to the study scale

3.2. Starting Points

- Format: GeoPackage (GPKG) containing geographic coordinates (X, Y)
- Define initiation zones for gravitational movements
- Can represent avalanche sites or rockfall source areas

3.3. Reference Table

- Format: Excel (.xlsx)
- Contains pairs of values (AAinf, ALE_max) defining propagation conditions
- Established empirically from field observations and documented events

4. PROPAGATION ALGORITHM

The core of the model is based on a step-by-step propagation algorithm using a Breadth-First Search (BFS) approach.

4.1. General Principle

1. Initialization at the starting point (coordinates X, Y)
2. Iterative exploration of the 8 adjacent neighbouring cells
3. Calculation of geomorphological indicators for each candidate cell
4. Comparison with the reference table to decide on propagation continuation
5. Progressive construction of the reachable impact zone

4.2. Calculated Indicators

For each candidate cell for propagation, two main indicators are calculated from the topographic profile connecting the starting point to the cell:

$$ALE = \left| \arctan\left(\frac{\Delta z}{d}\right) \right| \times \frac{180}{\pi}$$

Where:

• Δz = elevation at starting point - minimum elevation of profile (total elevation drop)

• d = total horizontal distance travelled

Normalized Area Below (AAinf):

$$AAinf = \int_0^1 Y_{norm}(X_{norm})\, dX_{norm}$$

Where the profile is normalized:

$$X_{norm} = \frac{\text{distance}}{\text{total elevation drop}}$$
$$Y_{norm} = \frac{\text{elevation}}{\text{total elevation drop}}$$

The area is calculated using the trapezoidal method.

4.3. Propagation Condition

For each candidate cell:

1. Calculate AAinf and ALE
2. Search in the reference table: identify the largest value AAinf_ref ≤ AAinf
3. Retrieve the corresponding ALE_max value
4. Decision: If ALE ≤ ALEmax → propagation continues, otherwise → stop

4.4. Distance Management

The model accounts for the actual geometry of the grid:

- Orthogonal neighbours (up/down/left/right): distance = DEM resolution
- Diagonal neighbours: distance = resolution × √2

5. RESULTS AND EXPORTS

- Format: Georeferenced GeoTIFF
- Binary or percentile value raster indicating reachable areas

STEP-BY-STEP: Watershed Delineation in QGIS

1. Concepts

A watershed (also named drainage basin) is calculated from:

- a Digital Elevation Model (DEM)
- flow direction derived from terrain
- an outlet point (where water exits the basin)

QGIS uses hydrological tools (GRASS or SAGA) to perform this analysis.

Required data and tools

- DEM (SRTM, ALOS, LiDAR, etc.)
- QGIS 3.x
- GRASS GIS tools (included in QGIS)

2. Step 1: Load the Digital Elevation Model (DEM)

1. Open QGIS
2. Go to Layer → Add Layer → Add Raster Layer
3. Load your DEM file

Check CRS

- Bottom-right corner → click CRS
- Use a projected CRS (e.g., UTM), not geographic (lat/long)

3. Step 2: Fill Sinks (Remove Depressions)

This ensures continuous water flow.

1. Open Processing Toolbox
2. Navigate to:
   GRASS → Raster → Hydrology → r.fill.dir
3. Set:
   a. Input raster: DEM
   b. Filled DEM: output file
   c. Flow direction: output file
4. Click Run
5. Outputs:
   a. Sink-filled DEM
   b. Flow direction raster

4. Step 3: Compute Flow Accumulation and Direction

1. In Processing Toolbox, open: GRASS → Raster → Hydrology → r.watershed
2. Set: Elevation: Filled DEM
3. Click Run
4. Outputs:
   a. Flow accumulation
   b. Flow direction

Tip: High accumulation values represent stream channels.

5. Step 4: Identify and Create the Outlet Point

1. Right-click Layers Panel → Create Layer → New Shapefile Layer
2. Geometry type: Point

3. Save the layer
4. Toggle Edit Mode
5. Place a point:
    a. On the main stream
    b. At the lowest point of the basin
6. Save edits and stop editing

6. Step 5: Delineate the Watershed

1. Open Processing Toolbox
2. Go to:

    GRASS → Raster → Hydrology → r.water.outlet
3. Set:
    a. Input flow direction: from Step 3
    b. Outlet point coordinates:

        Use the outlet point layer
4. Click Run
5. Output: Watershed raster

7. Step 6: Convert Watershed Raster to Polygon

1. Go to

    Raster → Conversion → Polygonize (Raster to Vector)
2. Input: watershed raster
3. Output: polygon layer

Result:

- Watershed boundary as a vector polygon

8. Step 7: Calculate Watershed Area

1. Open polygon attribute table
2. Click Field Calculator
3. Create new field:
    a. Name: Area_km2
    b. Type: Decimal
4. Expression: $area / 1000000

9. Optional Steps

- Extract Stream Network
    a. Use r.watershed accumulation threshold
    b. Convert raster stream to vector
- Create Sub-basins
    a. Use multiple outlet points
    b. Run r.water.outlet for each point

10. Common Errors to Avoid

- Outlet not placed on stream
- DEM not filled
- Wrong CRS
- Low-resolution DEM

General workflow for Watershed Delineation in QGIS

Alternative (Simpler) STEP-BY-STEP: Watershed Delineation in QGIS + SAGA GIS

1. Step 1: Load the DEM

1. Open QGIS 3.x
2. Go to Layer → Add Layer → Add Raster Layer
3. Load your DEM
4. Check CRS
    a. Ensure the CRS is projected (e.g., UTM), not geographic.

2. Step 2: Fill Sinks (Depression Filling)

Removes depressions in the DEM for proper flow analysis.

1. Open Processing Toolbox
2. Navigate to: SAGA → Terrain Analysis – Preprocessing → Fill sinks (Wang & Liu)
3. Input:
    a. Elevation: DEM
4. Output:
    a. filled DEM
5. Click Run

Result: a hydrologically corrected DEM

3. Step 3: Compute Flow Direction

1. Open Processing Toolbox → SAGA → Terrain Analysis – Preprocessing → Fill sinks (Wang & Liu)
2. Input:
    a. Elevation: Filled DEM
3. Outputs:
    a. Flow accumulation raster
    b. Flow direction raster
4. Click Run

Flow accumulation highlights streams.

4. Step 4: Create the Outlet Point

1. Layer → Create Layer → New Shapefile Layer
2. Geometry type: Point
3. Save the layer
4. Toggle Edit Mode
5. Place the point:
    a. On the main stream
    b. At the lowest elevation
6. Save edits and stop editing

5. Step 5: Delineate the Watershed

1. Processing Toolbox →SAGA → Terrain Analysis – Hydrology → Watershed Basins
2. Input parameters
    a. Flow direction: from Step 3
    b. Outlets: outlet point layer from Step 4
3. Click Run

Output:

- Watershed raster (drainage basin)

6. *Step 6: Convert Watershed Raster to Polygon*

1. Go to Raster → Conversion → Polygonize (Raster to Vector)
2. Input: watershed raster
3. Output: polygon layer

Result: vector boundary of the drainage basin

7. *Step 7: Calculate Basin Area*

1. Open the polygon attribute table
2. Click Field Calculator
3. Create a new field: Area_km2
4. Expression: $area / 1000000

Tips & Common Errors

- Place the outlet point on the stream
- Always fill sinks before flow calculation
- Ensure projected CRS
- Use high-resolution DEM if possible

Advantages of SAGA Method

- Easier than GRASS
- Faster workflow
- Ideal for small–medium basins

Disadvantage of SAGA method

- Slightly less control than GRASS for complex terrains

General workflow for Watershed Delineation in QGIS using SAGA GIS toolbox

Appendix 2: Additional indicators beyond those used and usable at the local scale (specific field inventories, use of available field inventory data)

Timber indicators

Timber volume harvested

Definition: Total annual volume of timber harvested from a stand (TVH_{total}). This base metric aggregates the volume of timber harvested across all tree species and all diameter classes.

Units: $m^3ha^{-1}yr^{-1}$.

Timber volume harvested by species and diameter class

Definition: Total annual volume of harvested timber separated by species and diameter class ($TVH_{species, DBH}$).

Units: $m^3ha^{-1}yr^{-1}$.

Productivity

Definition: Current annual volume increment per hectare (*VI*).

Units: $m^3ha^{-1}yr^{-1}$.

Stocking

Definition: Stocking volume per hectare of living trees (*V*).

Units: m^3ha^{-1}

Timber yield by assortment

Definition: Harvested timber by assortments (diameter, length) of round wood and industrial wood by species (*HTA*).

Carbon Storage

Above ground carbon

Definition: Dry mass of carbon contained in above ground living tree biomass (bole + branches + leaves; living trees).

Units: t ha^{-1}.

$$C_{above} = BM_{above} * CF$$

where BM_{above} is the above ground forest biomass (t. ha^{-1}) and *CF* is the carbon fraction of dry matter (t C * t d.m.$^{-1}$) given for broad-leaves or conifers (Table 1).

Table 1: Dry carbon fraction values

Tree type	Carbon dry fraction (CF)
Broad-leaf	0.48
Conifer	0.51
Default	0.50

Wood volume (m^3 ha^{-1}) method

Above ground carbon stock is calculated using wood volume by first converting wood volume into above ground biomass (IPCC 2006):

$$C_{above} = [V * D * BEF] * CF$$

where *V* is timber volume (m^{3}ha^{-1}), *D* is the wood density (t dry matter m^{-3}, Table 2), *BEF* is the biomass expansion factor for conversion of volume to above ground tree biomass (Table 3), and *CF* is the carbon fraction of dry matter (t *C* * t d.m.$^{-1}$) given for broad-leaves or conifers (Table 1).

Table 2: Wood densities of stemwood (tonnes dry matter/m^3 fresh volume)

Species or genus	Wood density (*D*)
Abies	0.40
Acer	0.52
Alnus	0.45
Betula	0.51
Carpinus betulus	0.63
Castanea sativa	0.48
Fagus sylvatica	0.58
Fraxinus	0.57
Juglans	0.53
Larix decidua	0.46
Larix kaempferi	0.49
Picea abies	0.40
Picea sitchensis	0.40
Pinus pinaster	0.44

Pinus strobus	0.32
Pinus sylvestris	0.42
Populus	0.35
Prunus	0.49
Pseudotsuga menziesii	0.45
Quercus	0.58
Salix	0.45
Thuja plicata	0.31
Tilia	0.43
Tsuga	0.42

Table 3: Biomass expansion factors (BEF)

Temperate Conifers	1.3
Temperate Broadleaf	1.4
Boreal Conifers	1.35
Boreal Broadleaf	1.3

Tree size method (DBH and Height) method

Above ground carbon stock (living trees) is calculated using the equations developed in Vallet *et al*. (2006) for aboveground tree volume (bole + branches). Above ground tree volume is calculated using tree DBH and height values, and volume is converted to dry carbon mass. Above ground dry carbon is calculated as

$$C_{above} = V_{sp} * D * CF$$

where V_{sp} (m^3) is above ground volume as given by

$$V_{sp} = form \frac{1}{40000\pi} c_{130}^2 * h_{tot}$$

where c_{130} is the circumference in cm at a height of 130 cm, h_{tot} total height in meters and *form* a unitless factor describing a tree's shape. For Norway Spruce and Douglass fir trees with a $c_{130} > 45$, form is calculated as

$$form = \alpha + \beta * c_{130}$$

and for all other tree species with a $c_{130} > 45$ it is calculated as

$$form = \alpha + \beta * c_{130} + \gamma * hdn$$

where α, β, and γ are species specific constants (Table 4) and *hdn* is a measure of a tree's hardness as given by:

$$hdn = \frac{\sqrt{c_{130}}}{h_{tot}}$$

For Douglas fir Beech, Scots pine, and Maritime pine trees with a c_{130} < 45, *form* is calculated as

$$form = (\alpha + \beta * c_{130} + \gamma * hdn)\left(1 + \frac{\delta}{c_{130}^2}\right)$$

For other species this small tree correction factor is not used.

Table 4: Parameters for tree volume calculations (from Vallet *et al.*, 2006)

Species	**α**	**β**	**γ**	**δ**
Sessile oak	0.471	-0.000345	0.377	
Douglas fir	0.534	-0.000530		56.6
Norway spruce	0.631	-0.000946		
Common beech	0.395	0.000266	0.421	45.4
Scot pines	0.297	0.000318	0.384	204.0
Maritime pines	0.235	0.000970	0.396	198.8
Silver fir	0.550	-0.000749	0.277	

Below ground carbon

Definition: Dry mass of carbon contained in below ground tree biomass.

Units: t ha^{-1}.

$$C_{below} = C_{above} * R$$

where *R* is the root-to-shoot ratio (Table 5).

Table 5: Root-to-shoot ratios for estimating below ground carbon mass

Forest type	Root-to-shoot
Temperate conifer (above ground biomass <50 t/ha)	0.40
Temperate conifer (above ground biomass 50-150 t/ha)	0.29
Temperate conifer (above ground biomass >150 t/ha)	0.20
Temperate Quercus (above ground biomass >70 t/ha)	0.30
Temperate broadleaf (above ground biomass <75 t/ha)	0.46
Temperate broadleaf (above ground biomass 75-150 t/ha)	0.23
Temperate broadleaf (above ground biomass >150 t/ha)	0.24
Boreal conifer (above ground biomass <75 t/ha)	0.39
Boreal conifer (above ground biomass >75 t/ha)	0.24

Wood Energy

For all Wood Energy indices only trees that are larger than 5 cm DBH are considered.

Above ground wood energy biomass

Definition: Above ground forest biomass that remains after timber harvest (the latter typically sawn timber and pulp wood), i.e., total above ground biomass excluding the extracted part of the tree bole. It is the total potentially available biomass in addition to the biomass contained in the marketable bole).

Units: t ha^{-1}.

Wood energy biomass (technically harvestable)

Definition: This is the amount of additional biomasswhich can actually be extracted from the stand. It depends mainly on the employed harvesting technology and harvesting system. Practically, it is impossible to extract 100% of the potentially available additional biomass in a stand (i.e. small twigs, needles and leaves will break off and remain in the stand).

Units: t ha^{-1}.

Above ground wood energy biomass harvest

Definition: This is the actually extracted amount of additional biomass. It can maximally be as high as Above ground wood energy biomass

Units: t ha^{-1}

Biodiversity conservation

The importance of including biodiversity aspects in forest management has been recognised in international political processes (Baskent & Keles, 2005; MCPFE, 2003), and management guidelines and practices have been defined to better conserve biodiversity in managed forests (through silviculture, timber harvesting etc.). For instance, dead tree retention, retention of trees with specific microhabitats (e.g. cavities) and tree species mixtures are proposed to improve habitat quality for forest-dwelling species. In ARANGE, the aim is to define a set of indices related to biodiversity that will allow partners to assess the efficiency of biodiversity conservation for different management scenarios at stand and landscape scales. All these indices can be implemented in most models used in ARANGE. When some models are not able to implement an index, it is mentioned in the description section.

Tree species diversity

Definition: Tree species diversity represents a direct biodiversity index. It is considered as a major feature of forest structure (Pommerening, 2002) and may influence forest functioning (see discussion in Nadrowski et al., 2010). It also impacts other forest biodiversity components such as floristic diversity.

Description: A widely used index to assess tree species diversity at stand level is Shannons's entropy index, H (Neuman & Starlinger, 2001), which takes into account the number of species in the stand and their relative abundance (by number of trees, basal area, biomass, volume, etc.). Using species-specific basal area, then it is defined as follows (living trees with a dbh $\geq$ 5cm):

$$\begin{cases} H = -\sum_{i=1}^{S} p_i \ln(p_i) \\ p_i = \frac{g_i}{G} \end{cases}$$

with S the number of species, g_i the basal area of species i (m^2)and $G = \sum_{j=1}^{S} g_j$ (m^2). Actually, Jost (2006) advises the use of the related true diversity index D which is defined as: D =exp(H)

This index can be interpreted as an "equivalent number of species" as it equals tree species richness when all species in the stand/plot share the same abundance. Otherwise, it is always inferior to tree species richness (and superior or equal to 1).

Tree size diversity

Definition : Tree size diversity is often considered in studies relating stand structure to biodiversity (McElhinny *et al.*, 2005). The main idea is that high tree size diversity increases the diversity of habitats for forest-dwelling species (Rouvinen & Kuuluvainen, 2005; Buongiorno *et al.*, 1994; Bagnaresi *et al.*, 2002).

Dead wood abundance

Definition: Dead wood volume is often considered a good surrogate for the diversity of saproxylic species (Martikainen *et al*., 2000; Grove 2002) as it provides habitats as well as resources for these species (Müller & Butler, 2010; Müller *et al*., 2008). Moreover, it is directly related to tree removal and tree retention practices, and as such constitutes a cornerstone to deal with the trade-off between timber production and biodiversity conservation. Although a study revealed that the correlation between saproxylic species richness and dead wood volume may not be high in temperate forests (Lassauce *et al*., 2011), probably due to a lack of potential species due to strong past human footprint, it is still used in many countries as an indirect indicator of biodiversity.

Description: The dead wood volume *DWV* ($m^3 ha^{-1}$) includes standing dead trees with DBH ≥ 5 cm and lying dead wood originating from trees with DBH ≥ 5 cm whatever the decomposition stage.

Abundance of large standing dead trees

Definition: The total abundance of dead wood is insufficient to assess biodiversity of saproxylic species (Lassauce *et al*., 2011). The diversity of dead wood pieces plays also a role (Müller *et al*., 2008; Brin *et al.*, 2009; Simila *et al*., 2003). Thus, it is important either to consider an index that allow quantifying diversity of dead wood pieces (size, the species, position (standing/lying), decomposition stages) or to target a specific component of dead wood such as standing dead wood or large woody debris. Standing dead trees (snags) contain more microhabitats for saproxilic species than living trees (Vuidot *et al*., 2011; Fan *et al*., 2003) and provide specific habitats for some species compared to lying dead wood.

Description: The abundance of large standing dead trees is defined here as the number of trees per hectare with a DBH superior or equal to *DLSD* cm for both conifers and broadleaves. For each tree species there is an annual probability for the downing of a dead tree (*pd*). For instance, in the case of Norway spruce *pd*=0.103 per year. These probabilities have been derived from literature values by researchers from BOKU. Here are the values for the most important species:

Table 6: Annual probability of dead tree downing for most important species

Norway spruce Silver fir European larch	European beech	Scots pine	Sycamore maple Common ash Birch	Pedunculate oak	Swiss stone pine
0.103	0.224	0.081	0.142	0.141	0.045

Bird habitat quality indicator

Bird habitat quality indicator is complementary to previous indices as they target specific species or specific group of species. This indicator must be developed with ornithologists/birds experts who are familiar with the study area.

Selecting bird species

Species listed under the Annex I of Birds Directive (Directive 2009/147/EC) should have a priority when searching for possible typical forest bird species. It is recommended to select not individual bird species, but a group of species which have various requirements with common elements and an extended distribution when examined as a group.

The group common element could be their nesting method: usualy in tree-holes. The reason for selecting this element is that the land use and cover changes due to human actions are the largest hazards for forest'sbirds biodiversity and population viability in Europe, especially to species present in old-growth forests. Actually, in the last years, the cave-dwelling birds are highly considered as good key species and umbrella species for nature conservation and protection.

The pre-selected group of typical forest bird species (see proposal in Table 7) consists of all the woodpeckers potentially present , the Tengmalm's Owl and the Eurasian Tree Creeper. The Tree Creeper is much smaller thus less demanding, while it has several similar elements with some woodpeckers. It is also highly depended on the tree's characteristics.

Table 7. Proposal of pre-selected bird species.

Bird species	Observed presence	Potential presence
Tengmalm's Owl (*Aegolius funereus*)		
Eurasian Wryneck (*Jynx torquilla*)		
Grey-headed Woodpecker *(Picus canus)*		
European Green Woodpecker *(Picus viridis)*		
Black Woodpecker *(Dryocopus martius)*		
Great Spotted Woodpecker *(Dendrocopos major)*		
Syrian Woodpecker *(Dendrocopos syriacus)*		
Middle Spotted Woodpecker *(Dendrocopos medius)*		
White-backed Woodpecker *(Dendrocopos leucotos)*		
Lesser Spotted Woodpecker *(Dendrocopos minor)*		
Three-toed Woodpecker *(Picoides tridactylus)*		
Eurasian Treecreeper (*Certhia familiaris*)		
Other species to be selected with local ornithologists/birds' experts		

Indicators for habitat quality

Dead wood, standing: Dying and dead trees have been recognized as a highly important factor for breeding and feeding of numerous animal and plant species. Specifically for cave-dwelling birds, the standing dead wood has even more significance. Standing deadwood (snags) above specific thresholds (see Table 8 below) can be used in accordance with the deadwood indicators (see above).

Unmanaged forests: This parameter has a similar requirement for nature conservancy as the dead wood. Moreover, in the areas where no forest management occurs, the forest ecosystem is closer to natural processes, so there is usually a balanced nutrient cycling, dead wood, complex structure, etc. which can support high levels of biodiversity. This is a qualitative indicator.

Veteran trees: There is evidence that the diversity and abundance of animal species are higher around veteran trees. The reason is that these trees develop really many micro habitats from the roots to the highest branches of the trees. When veteran trees are missing, then these micro-habitats are decreasing. In addition, often the veteran trees can be connected with the age of the forest stand.

Canopy cover: The canopy cover is connected to the general structure of the habitat, hence to the overall quality of habitat for birds. Medium cover-range is the most favorable for birds, because these forests have the best food availability (insects, good cover of herb- and shrub-layer), while remaining closed enough for sheltering and nesting. Too dense and too open cover-range conditions are suboptimal for birds for several reasons; mainly because the food availability is reduced.

Alien tree species: It's accepted that mixed forests are better for biodiversity and ecosystem services (more available habitats more chances to fulfilling birds' requirmeents)but this mixture should derive from indigenous tree species and not from alien tree species (for which there is no information how they are going to affect the forest ecosystems in a long term perspective).

Defining thresholds for habitat quality indicators

Indicator	Good	Medium	Poor	Remarks
Dead wood, standing (m^3/ha); for all regions excepted Meditteranean one	> 35	15 - 35	< 15	Only for standing dead wood, DBH > 30 cm
Dead wood, standing (m^3/ha); for Mediterranean zones	> 20	10 - 20	< 10	
Unmanaged forest (years)	> 100	20 - 100	< 20	
Veteran trees (n/ha)	> 20	10 - 20	<10	Maturity of stands, DBH > 50
Canopy cover (%)	60 - 80	80 - 90 and 40 - 60	> 90 Or > 40	Characterizes forest conditions of intermediate crown closure; if too dense no suitable ground layer will develop, if too open no forest microclimate will prevail
Tree species (basal area of alien tree species)	< 10 %		> 10 %	

Protection against natural hazards

Many mountain forests cover steep to very steep slopes (angle of 35 - 70°) and thus have an important protective function against natural hazards such as rockfall, snow avalanches, shallow landslides and erosion. The primary function of these protection forests is to protect people or asset from the impact of natrual hazards. The "key product" of these forests are the standing trees that act as obstacles to the acquisition of the initial conditions necessary to the release of mass movement hazards and/or the downslope propagation of these hazards

By definition, for calculating Protection indices only trees that are larger than 5 cm DBH are considered.

Protection against rockfalls hazards

Definition: In the case of rockfall, the forest is efficient only in the transit and deposit zones. There, the efficiency of the protection offered by a forest stand against rockfall depends on:

- The volume, the shape and the mass of the boulder.
- The initial fall height.
- The distance between the foot cliff and the entry in the stand. •
- The slope.
- The slope roughness and the dominant soil type.
- The length of the forested slope.

- The stand dendrometric parameters: stem density, basal area, mean diameter at breast height (mean DBH), tree species distribution. (trees >5cm DBH)

These values need to be collected/calculated at the scale of the versant in order to derive a value of the Probable Residual Hazard (PRH). The PRH is equal to the percentage of rocks that are able to pass through and exit a forested slope.

The tool Rockfornet (http://www.ecorisq.org/en/rockfornet.php) calculates this PRH.

Protection against snow valanches

Definition: Forests are effective against snow avalanches only in the release zones. The efficiency of the protection offered by a forest stand depends on:

- The mean tree height, which has to be at least equal to twice the maximum snow height.
- The value of canopy cover in winter. This variable impacts snow interception, its deposition on the soil, and the quality (heterogeneity) of the snow cover.
- The stand dendrometric parameters: stem density, basal area, and mean DBH. The above variables have a positive effect on the mechanical anchorage of the snow cover.
- The slope.
- The roughness of the forest floor.
- The size of gaps in the stand: they should not exceed 1.5 times mean tree height in the direct slope line.

The effect of the snow interception on the snow cover stabilization represents 70% of the protection provided by a forest stand. The mechanical anchorage represents 30% of the protection effect of a forest stand (Berger, 1997).

As for rockfalls, it is possible to calculate for a given stand an avalanche protection index (*API*) based on the ratio between the current stand parameters and the ones needed for an instantaneous optimal protection.

For calculating the *API* the main assumption is that for a given mean DBH the basal area is the dendrometric parameter that can be used to synthesize both the interception and the mechanical effects. Knowing the basal area needed to avoid a snow avalanche release, it is possible to calculate the *API* via the ratio (current stand basal area / basal area needed).

Description: The input data for the calculation of the *API* for one pixel located on a snow avalanche release zone (slope of the pixel between 28 and 55° and an elevation superior to 800m) are given in table 10.

Table 10: input data for the calculation of the API for one site (or pixel if using a GIS)

Forest stand			Topography		
Name	Abbreviation	Units	Name	Abbreviation	Units
Basal area	G	m^2/ha	Slope value	slope°	degree
Average Diameter at breast Height	$\overline{DBH}$	cm			

<u>For pure evergreen stands</u> then the formula for calculating the *API* is:

$$API = \min\left[\frac{G}{\left(0.2901^*\ \overline{DBH} + 1.494\right) \times \left(0.1333^*\ slope^\circ - 3\right)}; 1\right]$$

<u>For mixed and pure deciduous (including larch) forests (less than 70% of evergreen stems dbh>5cm)</u> the formula for calculating the *API* is:

$$API = \min\left[\frac{G}{\left(0.528^*\ \overline{DBH} + 1.5566\right) \times \left(0.1333^*\ slope^\circ - 3\right)}; 1\right]$$

An API of 1 expresses the fact that the protection is very efficient.

Protection against landslides and erosion

Definition: For this category of phenomena and before the results coming from modeling works using landslide models able to take into account the role played by stands, we propose to use simple recommendations provided by NaiS (Frehner et al. 2005) and the French GSM (Gauquelin & Courbaud 2006).

Description: Forests can reduce the likelihood and extent of landslides or erosion by mechanically reinforcing the soil through its rooting system, and can positively influence the water balance in the soil through interception, transpiration and enhanced soil permeability (Frehner et al. 2005). Well-developed forests that are multi-layered provide the greatest protection from both landslides and erosion. The assumption being that a well-structured above ground forest will have a corresponding well-structured and extensive rooting system that will minimize landslide potential.

Guidelines suggest that in areas where landslides may originate that the minimum profile is a forest that is multi-layered and has canopy coverage $\geq$ 30%-40% canopy coverage. The ideal profile is a multi-layered forest with $\geq$ 60% canopy coverage.

Landslide Protection Index (LPI) is qualified by using forest cover (% projected canopy cover area: cannot be superior to 100% ; all trees with a dbh ≥ 5cm) only as clear thresholds for stand stratification are not available:

- Forest cover < 30% : LPI=low
- Forest cover ≥ 30% and <60% : LPI=medium
- Forest cover ≥ 60% : LPI=high

Gefördert durch:
Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz
aufgrund eines Beschlusses des Deutschen Bundestages